AN APPLICATION OF DIGITAL VIDEO RECORDING AND OFF-GRID TECHNOLOGY TO BURROWING OWL CONSERVATION RESEARCH

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Through this research, engineering students and conservation biologists constructed an off-grid video system for observing western burrowing owls in El Paso, Texas. The burrowing owl has a declining population and their range decreasing, driving scientists' interest to see inside the den for observing critical nesting behavior. Texas Parks and Wildlife Department (TPWD) biologists wanted videos from inside the dark, isolated hillside owl burrows. This research yielded a replicable multi-camera prototype, empowering others to explore applications of engineering and wildlife monitoring. The remote station used an off-the-shelf video recording system, solar panels, charge controller, and lead acid batteries. Four local K-12 science educators participated in system testing at Lake Ray Roberts State Park through the Research Experiences for Teachers (RET, NSF #1132585) program, as well as four undergraduate engineering students as senior design research.

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iii

LIST OF TABLES vii

LIST OF ILLUSTRATIONS viii

CHAPTER 1 INTRODUCTION 1

1.1 Problem Definition and Motivation 1

1.2 Burrowing Owl Video Project Objectives 1

1.3 Scientific Value of this Research 2

CHAPTER 2 SUPPORTING KNOWLEDGE 4

2.1 Species and Habitat 4

2.2 Related Work 7

CHAPTER 3 DESIGN CONSIDERATIONS 11

3.1 Specifications and Constraints 11

3.2 Methods 13

3.2.1 Project Development 13

3.2.2 Data Collection from the Field Site 17

3.2.3 Data Transfer, Review and Long-Term Storage 18

3.2.4 Considerations for the Longevity of the Research 19

3.3 Equipment Selection 19

3.3.1 Most Comparable Vendor-Built Products 19
3.3.2 Alternative User-Built Approaches 21
3.3.3 Digital Video Recording Systems Overview 22
3.3.4 Selected Recording System and Off-Grid Equipment 23
3.3.5 Solar Panel Mount 25
3.3.6 Camera Mounts and Access Tunnels 27
3.3.7 Cost Overview 31
3.4 Preliminary Equipment Study and Power Considerations 32
3.4.1 H.264 Compression for Video Storage 34
3.4.2 Motion Detection 34
3.4.3 Remote Access to the DVR 36
3.4.4 Intro to Going Off-Grid with Solar Panels 41
3.4.5 Sizing the Solar Panels and Battery Backup 42
3.4.6 Wild Watch and Power Management with RET 46
3.4.7 Outdoor Equipment Study with Undergraduate Team 58
CHAPTER 4 FINAL TESTING AND DISCUSSION 68
4.1 Final Site at El Paso, Texas 68
4.1.1 Site Layout 68
4.1.2 Performance 71
4.2 Broader Impacts 74

4.3 Avenues for Continued Research 77

4.3.1 Modifications to Improve Efficiency 77

4.3.2 Wireless Access and Establishing a Multi-Agent Network 78

4.3.3 Incorporating Video Data to Environmental Monitoring Stations 80

4.3.4 Other Extensions 81

CHAPTER 5 CONCLUSION 84

APPENDIX A SAMPLE MOTION DETECTION CODE 85

APPENDIX B PARTS LIST FOR OFF-GRID PROTOTYPE AT RIO BOSQUE 87

BIBLIOGRAPHY 89

LIST OF TABLES

Page

TABLE I Comparable products 21

TABLE II Parts list of comparable recording system 31

TABLE III Parts list of selected recording system 32

TABLE IV Cost of prototype at Rio Bosque 32

TABLE V Power consumption reference points 43

TABLE VI Power consumption for basic off-grid 44

TABLE VII Battery capacity for basic off-grid 44

TABLE VIII Solar panel output for basic off-grid 45

TABLE IX Solar panel output per day 45

TABLE X Sample usage scenarios 56

TABLE XI Power consumption 57

TABLE XII Battery capacity 57

TABLE XIII Solar panel output 58

TABLE XIV Cloud cover and solar quality 62

LIST OF ILLUSTRATIONS

Page

Fig. 2.1. Den and tunnel layout at Rio Bosque 6

Fig. 2.2. Blue barrel den and tunnels 7

Fig. 2.3. Den access bucket system 7

Fig. 3.1. Project components 14

Fig. 3.2. Block diagram of the basic off-grid prototype 15

Fig. 3.3. Equipment box layout 15

Fig. 3.4. Swann™ 8-Channel DVR with 4 Cameras 24

Fig. 3.5. Swann™ PRO-550 infrared cameras 24

Fig. 3.6. Side views without panels and close up of mount 26

Fig. 3.7. Front view of the frame and rear view with equipment 26

Fig. 3.8. Threaded-pipe frame 27

Fig 3.9. Example bin and a den access diagram 28

Fig. 3.10. Flexible PVC coupling for the tunnel cameras 29

Fig. 3.11. Burrow layout at Rio Bosque with cameras 29

Fig. 3.12. Top view of the burrow layout 30

Fig. 3.13. Atrium grate used as camera mount 30

Fig. 3.14. DVR file naming scheme 33

Fig. 3.15. Outdoor camera positioned at a bird feeder 33

Fig. 3.16. Home setup and DVR display 33

Fig. 3.17. Simple state diagram for motion record 35

Fig. 3.18. Local viewing scenario (shared network) 37

Fig. 3.19. Swann™ live viewing 38
Fig. 3.20. Swann™ network configurations 38
Fig. 3.21. Remote viewing scenario (outside the network) 39
Fig. 3.22. Port forwarding in firewall settings 39
Fig. 3.23. DVR device information on router configurations 40
Fig. 3.24. Swann™ Remote (mobile) viewing 41
Fig. 3.25. Spliced power cable and port 47
Fig. 3.26. RET install at IDB 47
Fig. 3.27. Two different mice visited the burrow 48
Fig. 3.28. Screen capture of the RET field test 48
Fig. 3.29. P550 and P640 in a 17" tall den with 5" tall nest 50
Fig. 3.30. P550 and P640 in a 14" tall den with 5" tall nest 50
Fig. 3.31. P550 and P640 in a 14" tall den with 9" tall bird 51
Fig. 3.32. P550 and P640 in a 17" tall den with 10" tall housecat 51
Fig. 3.33. Tripod and den floor setup 52
Fig. 3.34. P550 in a 14" den height and 17" den height 52
Fig. 3.35. Arduino™ UNO and prototype with PIR sensor 53
Fig. 3.36. Block diagram of the Wake-up prototype 54
Fig. 3.37. Preliminary schematic of the Wake-up prototype 55
Fig. 3.38. Preliminary PCB design 55
Fig. 3.39. Cameras facing a small pond 58
Fig. 3.40. Setup by the pond at IDB 59
Fig. 3.41. Solar quality for October 64

Fig. 3.42. Load status for October 64
Fig. 3.43. Solar quality for November 65
Fig. 3.44. Load status for November 65
Fig. 3.45. Bird taking flight toward the camera 66
Fig. 3.46. Samples of a small buck, a doe running and a curious buck 66
Fig. 3.47. Buck scraping a tree at night (sequence) 67
Fig. 3.48. Chase scene on channel 5 (sequence) 67
Fig. 4.1. Entrance to and installation of the artificial burrow 68
Fig. 4.2. Running the cables between access bins 69
Fig. 4.3. Camera mount and tunnel access 69
Fig. 4.4. Installing the frame and equipment box 69
Fig. 4.5. Front (angled) and rear view of the prototype 70
Fig. 4.6. Equipment box at Rio Bosque 70
Fig. 4.7. Burrowing owl on install day 71
Fig. 4.8. Screen capture of February field test 72
Fig. 4.9. Burrowing owl at the far- and close-end of the tunnel 73
Fig. 4.10. An owl exploring and an incubating owl 74
Fig. 4.11. Cottontail rabbit at site A 74
Fig. 4.12. Initial field study at IDB with RET 77

CHAPTER 1

INTRODUCTION

1.1 Problem Definition and Motivation

This thesis discusses the development and application of an off-grid video monitoring system to aid in conservation studies of western burrowing owls. The declining population and shrinking migratory range of these raptors ranks them as a Species of International Conservation Concern [1], driving scientists' interest to see inside the nest. Texas Parks and Wildlife Department (TPWD) biologists needed an affordable means of observing owl activity inside the dark, isolated burrows in the hillsides of El Paso, Texas. TPWD biologists, Lois Balin and Richard Heilbrun, wanted to record video of the birds' nesting behavior in the successful artificial burrows at the Rio Bosque Wetlands Park (hereafter Rio Bosque for brevity). Since the owls travel deep into the hillsides at the off-grid park, this underground installation of infrared (IR) cameras was a unique application of digital video recording (DVR) technology to wildlife monitoring.

As intriguing cross-disciplinary research, this work simultaneously cultivated partnerships between the disciplines and encouraged public participation through science, technology, engineering, and mathematics (STEM) outreach.

1.2 Burrowing Owl Video Project Objectives

Without cameras in the burrows, the biologists would routinely wait hours for activity to occur at the tunnel entrances. Human disturbance limited the monitoring effort to the use of a telescopic lens from afar, leaving no way to observe nesting behavior

within the den. Adding video recording of the site activity improved the quality and quantity of visual data used for conservation studies of the burrowing owl, compared to the time consuming monitoring methods by on-site human observers [2]. The final prototype presented here enabled unseen nesting behavior of the burrowing owl. Additionally, the final site was located across the state of Texas from the University of North Texas (UNT, Denton, Texas). The long distance research involved frequent communication and online training for the longevity of the monitoring project at Rio Bosque.

1.3 Scientific Value of this Research

The project, motivated by national and global initiatives for conservation studies, aimed to facilitate the collection of valuable visual data relevant to the behavior analysis of the burrowing owl, a species of conservation concern in some countries, such as Canada [1] and parts of the United States [3]. The evolution of this off-grid video setup explored a low-cost, off-the-shelf, user-built solution to video monitoring of wildlife. This collaborative project hoped to inspire intellectual curiosity and provoked questions for continued research. It offered the potential to address some of the power and data storage challenges presented by similar video monitoring practices. The challenges at hand for monitoring the burrowing owls embodied the growing need for interdisciplinary communication and cooperation to improve conservation research.

Working with TPWD biologists to identify the location and size of the system both ensured scientifically valuable data collection and strengthened cross-disciplinary perspectives. The system reinforced conservation efforts of the TPWD Urban Wildlife

Program biologists, and it can be replicated by scientists and community members elsewhere to explore engineering applications in wildlife studies.

To better understand the contributions of the video surveillance system, the next chapter discusses the burrowing owl research underway by TPWD Urban Wildlife Program biologists in El Paso prior to incorporating cameras.

CHAPTER 2

SUPPORTING KNOWLEDGE

2.1 Species and Habitat

The species of interest for the final prototype of the wildlife monitoring system was the western burrowing owl, *Athene cunicularia hypugaea*, a unique subspecies of the burrowing owl. The western burrowing owl, henceforth referred to as burrowing owl, has a shrinking migratory range and declining population [1]. In 2009, the owls were listed as a Species of International Conservation Concern and Endangered in Canada [1], among other conservation rankings. As discussed later in this section, Texas Parks and Wildlife Department (TPWD) Urban Wildlife Program biologists have built a series of artificial burrows in Rio Bosque Wetlands Park (hereafter, Rio Bosque) as part of conservation research on this species. In assessing whether these burrows are successful, they were left asking: Are owls occupying the artificial nests in El Paso? Are the individuals newcomers to the site? Are they yielding successful offspring? Are the birds experiencing predation events within the burrows?

Answering such questions by studying the owls in the wild was time consuming and unreliable. The artificial burrows are located in the harsh desert environment, lacking access to power and facilities. Researchers and volunteers would endured these conditions, hoping to witness undisturbed owl activity. Although repetitive observations were made, lack of continuous monitoring led to sporadic data [2] and was heavily dependent on a number of variables, impeding the observation of roosting behavior to advance knowledge of these unique birds. Adding the camera system

allowed them to simply swap a digital video recording unit full of potentially meaningful visual data to review at the office.

Videos from a similar project completed at the University of Reading [4] motivated TPWD biologists to explore the application of video technology within burrowing owl nests. Lois Balin, TPWD Urban Wildlife Program biologist in El Paso, recommended the final sites at Rio Bosque, based on prior research with these owls [1].

Despite their conservation status, the burrowing owls face the loss of natural habitat for nesting [1]. They opportunistically occupy burrows from other ground-dwelling mammals, such as ground squirrels and prairie dogs that are undergoing population management. Artificial burrows have provided alternative living spaces, aiming to mitigate the scarcity of naturally-constructed sites of other burrowing mammals [1]. Owls have been sighted at the artificial burrows throughout Rio Bosque over several years [5]. This suggested that installing cameras on artificial burrows could avoid the challenges of installing cameras within a poorly understood natural burrow. Natural burrows introduced many unknowns essential for application, such as den shape, depth, wall stability, and other critical aspects of long-term installation of underground cameras.

The Urban Wildlife Program biologists in El Paso created a tunnel system and den out of 4" PVC-Schedule 40 and half of a hard-plastic barrel, respectively. TPWD found that the owls preferred at least one turn in the tunnel [1], so a 4" PVC elbow fitting added a turn before the den. A barrel provided the sturdy dome housing but was open at the bottom, leaving an earthy den floor rather than a plastic floor. Balin's research [1] involved carefully attaching metal identification bands on untagged fledglings at the

artificial den sites to monitor returning individuals. Therefore, there was a need to easily reach inside the den from above to pick up a bird. Thus, an access system was added to the top of the den. Tunnel entrances could be blocked off and the den opened from overhead to reach the owls.

The burrow layout is shown in Fig. 2.1. Birds would enter the tunnels on the hillside, travel down 4' of tunnel, turn to go another 4' of tunnel, and arrive at the den [1]. They could continue straight through the den to a tunnel system mirrored on the other side, leading back out to the hillside. The tunnels were slightly sloped to allow water runoff out of the tunnels in case of rain.

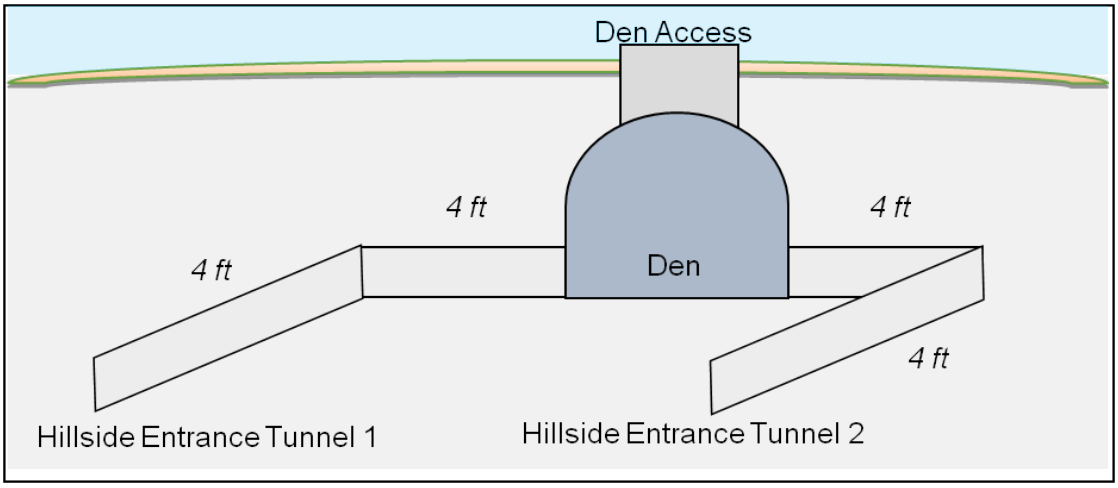


Fig. 2.1. Den and tunnel layout at Rio Bosque

The den access design used a weighted bucket sitting atop a removable platform at the bottom of a main 5-gallon bucket, affixed to the den below (see Fig. 2.2). The den (blue), tunnels (black), and most of the main bucket (white) were buried into the hillside. The top of the main bucket stayed above ground for easy access.

Fig. 2.2. Blue barrel den and tunnels

The inner bucket lowered into the main bucket, to rest on the removable platform, separating the biologist from organisms inside and protecting against nest predation from the surface. The biologists could lift out the inner bucket and platform to expose the den, as illustrated in Fig. 2.3 (Photos by L. Balin).

Fig. 2.3. Den access bucket system

2.2 Related Work

With advancements in video technology, there exist many wildlife video monitoring projects around the world, spanning from treetop bird nests to polar bears in the remote Arctic tundra. A theme that appeared in the literature was intended use of the wildlife videos: research, surveillance, enforcement, and education. Cox [2] presented a concise categorization of literature by study objective, where the majority of

nest cameras were used to observe nest predation studies, feeding ecology, and adult behavior. The unique application of video technology presented in this paper combines these uses into year-round observation of burrowing owl activity from cameras placed within an underground artificial dwelling.

Recognizing developments in video technology and its application to wildlife sciences, Brown [6] and Ribic [7] provided a nice overview of available technology and discussed several case studies. In 2012 [7], the authors not only discussed the methods for several nest monitoring scenarios, but also gave suggestions depending on the study objectives. The projects described in the literature followed two approaches of adding video recording to monitor wildlife: vendor-built systems made specifically for wildlife monitoring, and user-built systems with outdoor cameras [2].

One of the leading, commercially available, self-contained digital video recording systems used for wildlife monitoring by large research organizations at the time of this research in 2014 was SeeMore™ Wildlife Systems [8]. Since its original goal to create a system for live video monitoring in the harsh Alaskan environment, this Alaska-based company installed hundreds of cameras worldwide over six years [8]. These proprietary systems are responsible for much of the incredible footage broadcasted by large organizations such as the National Geographic Society™ productions. ZatzWorks Inc. offered helicopter-mounted video technology for the stunning video segments often seen on large television programming productions and others, according to the company's webpage. With such high quality and proven results from hundreds of camera installations, the cost was steep compared to some of the other user-built approaches [2]. These video systems were likely expensive because they provide high-

quality, maintenance-free, year-round off-grid designs that could offer hot-swap hard drives for data collection and wireless live streaming of video. The company claimed to have developed the first remote thermal imaging wildlife camera system, using the Thermal-Eye™ 300D infrared camera [8].

An application of the SeeMore™ monitoring technology in context of the video monitoring of burrowing owl nests, could be the Castle Rock Seabird Project in Arcata, California [9]. Aerial observations were not an option for studying the nocturnal, shallow-burrowing seabirds nesting at Castle Rock off the coast of Crescent City, California [9].

From the user-built perspective, Golightly took an interesting approach by using a standard surveillance system consisting of a digital video recording device and outdoor cameras [10]. In 2011, Golightly described the equipment used and performance in terms of data collection and battery replacement [10]. This off-the-shelf design contrasted that of specialized systems developed commercially, while also presenting an opportunity to improve design and implementation. An apparent advocate of user-built systems, Cox stated that "the first question researchers should ask is whether off-the-shelf equipment will suffice to meet their study objectives" [2].

Another user-built approach could move from simplicity to optimization and in some cases the development of customized low-power processing boards for video data acquisition and storage. Engineering students at the University of Reading developed such a customized system to facilitate Joachim's Ph.D. research on the little owl (*Athene noctua*) [4]. During original discussions about an application of the video system TPWD biologists highlighted the little owl nest box project in [4, 11]. The nest box cameras recorded owl behavior throughout the breeding season, and with the

application of infrared video technology, the application [4, 11] was a model for the prototype developed in this burrowing owl research. Unfortunately, specific information on the equipment was not available, only video clips of the owls and basic descriptions of the project had been released.

However, a quote from the wildlife camera company recommended by researchers with the little owl project was requested. Closewatch Nest Box & Wildlife Cameras™ systems retailer produced a quote of seemingly off-the-shelf equipment, sparking the idea of a partnership between engineering students and TPWD biologists to develop a more affordable prototype, and take it off-grid. At the University of Missouri, students from engineering and biology collaboratively installed motion-triggered cameras in 2011, revealing incredible images of bears, bobcats, and other wildlife [12].

CHAPTER 3

DESIGN CONSIDERATIONS

3.1 Specifications and Constraints

This research aimed to identify, test, and apply a user-built digital video recording (DVR) approach [2, 7, 10] to the burrowing owl sites at Rio Bosque Wetlands Park (Rio Bosque). The Texas Parks and Wildlife Department (TPWD) biologists needed an off-grid system that they could maintain long-term, capable of recording infrared video from inside artificial owl burrows. The project scope was identified in collaboration with the TPWD biologists to ensure that their needs were met and to facilitate appropriate research questions.

In short, the goal was to lower the prototype cost compared to other vendor-built systems, yet preserve the core features necessary for the burrowing owl research. Reliable cameras can increase the likelihood of witnessing burrow activity, while reducing human influence on such wildlife behavior.

Key to the design was to modify the existing TPWD artificial burrow design discussed in section 2.1 to accommodate cameras, rather than reinventing the setup, since it was known to be successful year after year. Selecting cameras for the final underground orientation at Rio Bosque required infrared (IR) video capability and a DVR with sufficient internal memory for a long field deployment. The DVR needed to support an external hard drive to the DVR for data backup. Three cameras were necessary for the burrow layout, though more could be beneficial for expanding to nearby sites.

Both the cameras and DVR needed to be affordable compared to the quote received from Closewatch Nest Box & Wildlife Cameras™ ($2300 USD), a similar wildlife camera system configured and installed professionally. Reducing the cost of the recording equipment provided room in the budget for taking the system off-grid. Ideally, the system would also explore motion triggered recording, but failure to incorporate this would not inhibit the system's ability to archive video of the owls. A series of equipment studies and field tests yielded such a remote wildlife monitoring station. Microphone capability and wireless real-time access were optional for this study.

The initial field testing was done locally at Ray Roberts Lake State Park - Isle du Bois (IDB, Pilot Point, Texas). For the final testing, TPWD biologists selected two candidate sites at Rio Bosque based on their existing research and observations of natural and artificial burrows in the Trans-Pecos and Panhandle Regions [1]. A multitude of environmental challenges existed at the final sites such as high temperatures, humidity, insects and mammals, and dust. To combat these issues, a weatherproof case was selected with shading provided by the solar panels, along with heat-sinking properties of the earth below the equipment case, and use of ventilation and sealants.

Continued use of the prototypes for burrowing owl research at Rio Bosque extends beyond the author's participation. Therefore, ease of setup, use, replication, and dissemination were considered from the beginning.

Additional planning and preparation prior to field installation was incorporated to reduce harm imposed on the environment. Park rangers and property managers provided guidance and advisement on restrictions, such as the type and number of

vehicles allowed off path for installation. One of the final sites at Rio Bosque was about 100 yards off of the driving path, so the equipment was transported with hand-trucks and wheelbarrows.

Furthermore, the research efforts were mindful of the regulations and professional standards including those of the FCC regarding closed-circuit television (CCTV), and the IEEE 937-2007, IEEE 1013-2007, IEEE 1562-2007, and IEEE 1857-2013. The cameras were buried in the burrows, avoiding the privacy concerns associated with cameras mounted in public areas.

3.2 Methods

3.2.1 Project Development

The effort followed applied research, adding digital video and off-grid technology to an ongoing wildlife monitoring project. The overall strategy depended on appropriate project selection and organized collaboration, with consideration for project longevity. Consulting with the TPWD Urban Wildlife Program biologists about their research needs and current species of concern led to the selection of the burrowing owl monitoring project. Three major tasks were identified: (1) construct a prototype, (2) refine and test at a local outdoor site, and (3) deploy at the burrowing owl site. Fig. 3.1 shows the various aspects of this work with equipment considerations in the top portion and implementation on bottom. For example, the power aspect consisted of energy collection, power storage, and power management.

Intended to be replicated, the system used at its core: a consumer-ready video surveillance system, solar panels, and lead acid battery. Instead of the typical wildlife

camera options that required a data and battery swap every few days to every week [2, 10], this system needed to collect several weeks of data at a time. A pro-active design approach was taken for the batteries by use of a charge controller, the DVR by configuring to auto-reboot, and the underground cameras by incorporating a way to access them for maintenance or repositioning at the tunnels.

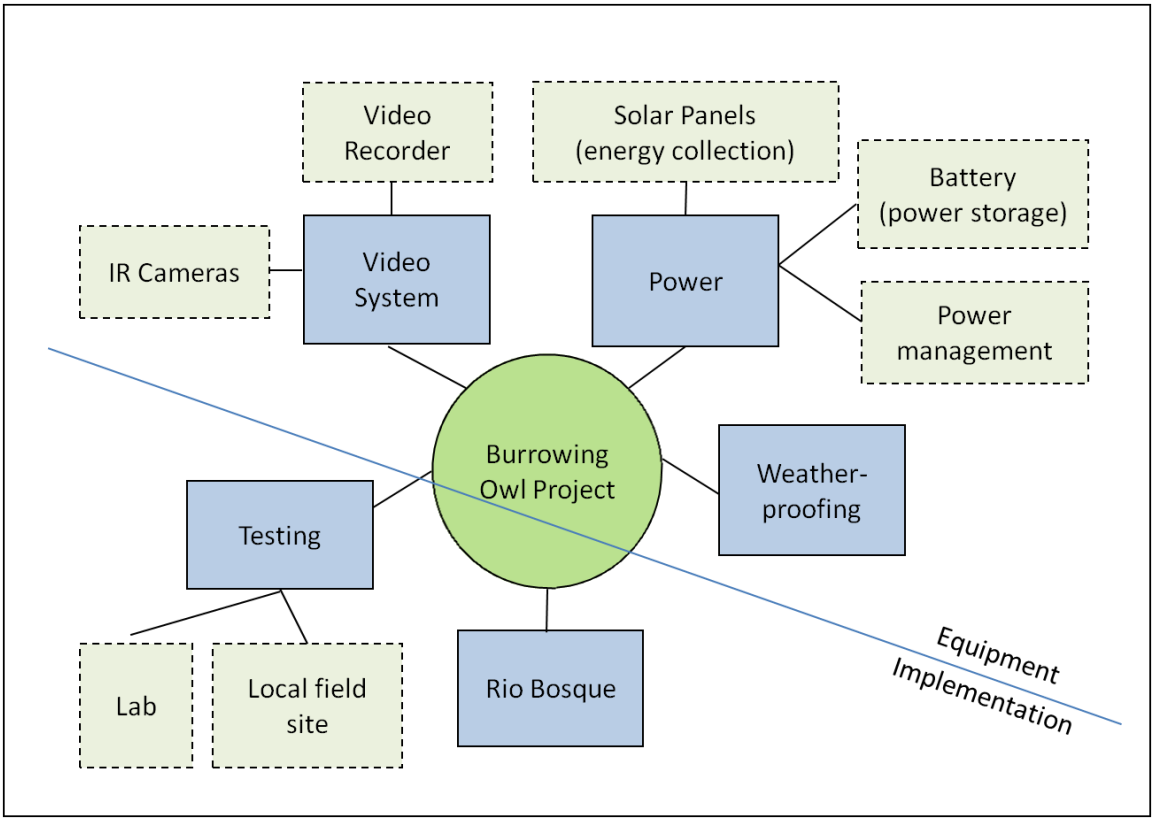


Fig. 3.1. Project components

Power was continuously supplied to the 12V DC load (DVR and cameras) from the battery bank. The charge controller regulated the power coming in from the solar panels to properly charge the deep-cycle battery, and offered protected load terminals (see Fig. 3.2).

In an attempt to keep the equipment cooler in the summer months, the solar panels were mounted to shade the equipment box below. In El Paso, the equipment box

was shallowly buried to allow the ground to serve as a heat sink. Housed within the equipment box were the battery bank, charge controller, and DVR as shown in Fig. 3.3. A sealed junction box next to the charge controller provided a passage for the camera power and video cables, as well as the solar panel input cables. At the load terminals of the charge controller, the cameras and DVR were connected in parallel. The layout was similar to the user-built DVR systems depicted in [2, 10, 13].

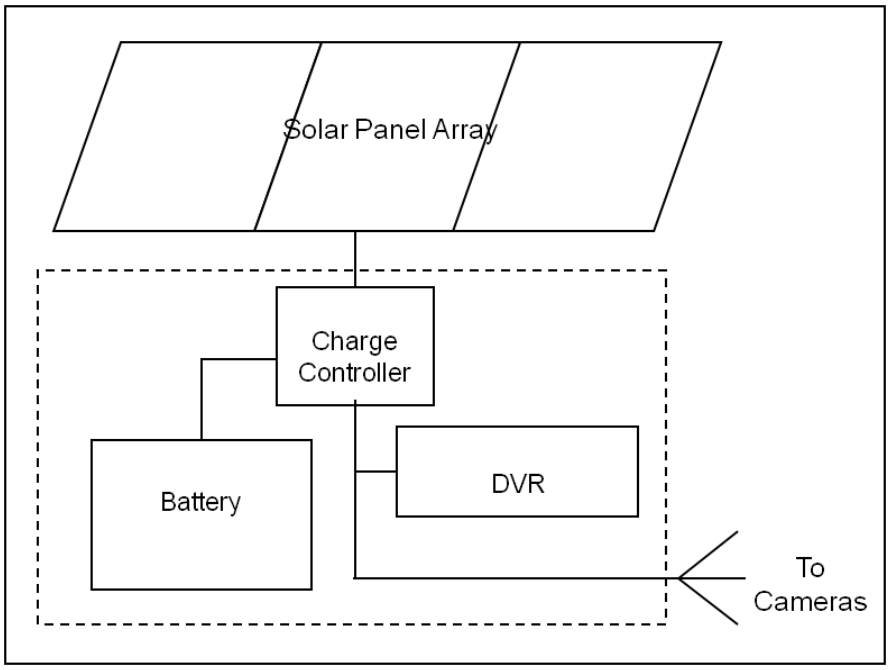


Fig. 3.2. Block diagram of the basic off-grid prototype

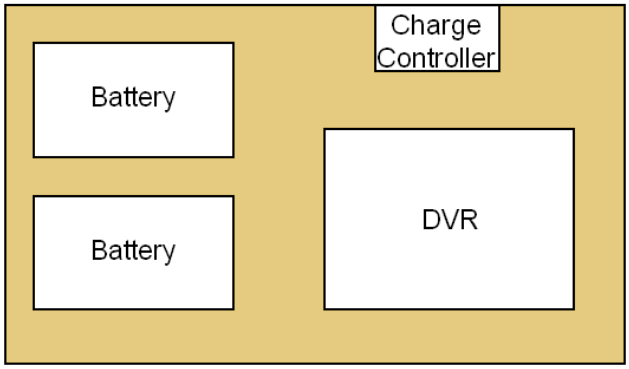


Fig. 3.3. Equipment box layout

To acquire meaningful views, the biologists requested a camera above the den, and a camera at each tunnel elbow. The den camera was needed to view general movement, nest formation, egg laying and hatching, feeding patterns, and predation. A camera was mounted above the den, peering through the platform of the main bucket. The elbow cameras helped the biologists see if the entering bird had an identification band, type of food they brought to the nest, face markings, relative size to other visitors, and front view of nest predators entering the burrow. Both the den access design and functionality were preserved because the TPWD biologists and volunteers were already familiar.

To help expand the project reach, opportunities were embraced to include diverse participants in meaningful ways. The project involved four K-12 educators through the Research Experiences for Teachers Site (RET, NSF Grant Num. 1132585) at University of North Texas (UNT, Denton, Texas) during the summer of 2013 to help conduct the initial field test and delve into power consumption challenges. Then, what began with the mentorship of an undergraduate engineering student grew to four that participated in the next phase of local testing in the fall of 2013. Local volunteers helped install the Rio Bosque prototypes and learned about the equipment first-hand in early spring of 2014.

Both the local testing and the final installation followed a set-it-and-forget-it approach with long deployments with occasional site checks. Part of the local field testing involved a couple of full-month deployments to observe how the system performed on longer cycles more similar to the end use at Rio Bosque. The install schedule at IDB was more lenient because there was not an intended organism or

event for observation, while at Rio Bosque it was important to install several weeks prior to breeding season for the burrowing owls. A single prototype was deployed at IDB from June-November 2013, and two prototypes were installed in early 2014 one-half mile apart at the final site in El Paso.

3.2.2 Data Collection from the Field Site

Once the hard drives were full, the biologists needed to either (1) swap the DVR, or (2) swap the hard disk drive (HDD) from the field with a formatted empty one from the office [2, 14]. Upon visiting the Rio Bosque site, it was elected to swap DVRs instead of HDDs due to the particularly dusty, windy environment. The pros outweighed the cons for this application, though swapping HDDs remained a less expensive option for environments/scenarios in which swapping HDDs was feasible. Also, the DVR selected for this research stored the H.264 video files on the internal HDD in a format not easily recognizable by Windows® or Mac® operating systems. However, the format of the USB connected storage drive was FAT32, which was compatible, allowing simple transfer and review on a computer.

Swapping the full DVR in the field allowed better cleaning and preparation of the DVRs and HDDs at the office. The DVR could be more effectively cleared of dust and a proper maintenance check could be performed at the office. For the TPWD biologists to swap the DVR at both prototypes, they needed two DVRs in the office ready for the swap. The DVRs at the office would be used for reviewing, backing up data from, and reformatting the field hard drives for the next field deployment. At the office, the next set of DVRs to be deployed would be configured and configurations verified. Out in the

field, the two cleared DVRs would replace the field DVRs for the next month, allowing the biologists to review the data back at the office.

3.2.3 Data Transfer, Review and Long-Term Storage

Data on the internal hard drive could be reviewed locally on the DVR by connecting a monitor via VGA cable. To transfer the contents off of the DVR, the files from the internal HDD of the DVR were backed up to the USB drive for review on a computer using the Swann™ PlayBack or AVIGenerator software. The data is backed up to a USB storage drive by following the on-screen prompts, which are also summarized in the supplemental DVR guide generated through this work.

When reviewing the files, it was important not to fast forward too quickly so as not to miss a meaningful event [10]. There was an interesting difference in the fast forward feature of the DVR compared to the Swann™ PlayBack software. Reviewing data only up to 8x fast on the DVR was found to be acceptable, which matched the up to 8x faster than normal reviewing speed witnessed by Golightly [10] in 2011. However, reviewing the data on a computer using the Swann™ PlayBack software allowed speeds of up to 16-32x faster than normal without missing events longer than 2 seconds in duration, outperforming the design presented in [10] in 2011 that allowed 8x faster review. The difference seemed to be the way the DVR executed fast forward on the compressed file compared to the computer software. The DVR appeared to skip frames according to speed selection to move forward faster in the file, while the Swann™ PlayBack software actually displayed all frames faster.

For more long term storage, the conservation biologists could consider submitting the archived video files to national repositories, such as the Macaulay Library [15]. The videos would then be posted online for open-access review and might avoid TPWD housing such large amounts of archived video.

3.2.4 Considerations for the Longevity of the Research

In addition to on-site installation and training, online training sessions were conducted and supplemental guides were generated, with corresponding video clips, to highlight relevant information from the lengthy product manuals. These efforts created a collection of product manuals, installation guides, and training documents with videos, for knowledge transfer beyond the author's participation. Also, each product needed to offer technical support phone lines and reference materials made available online.

3.3 Equipment Selection

The equipment for the final prototype included: a DVR, four infrared outdoor cameras, a 300 W solar panel array and charge controller kit, batteries, mounting materials, and an outdoor equipment box.

3.3.1 Most Comparable Vendor-Built Products

Browsing the SeeMore™ Wildlife Systems product webpage, their most comparable system to the prototype design was the RemoteDVR™ - Basic System priced at $6450 [8]. In addition to purchasing the Basic System, the client must supply two 55 Ahr deep-cycle batteries for power storage. The RemoteDVR™ system's 160 W

solar panel array and charge controller, together with the 110 Ahr battery bank, only provided power for 12 hours per day [8]. A power upgrade could be selected (+$950) to run 24 hours per day [8].

The system would record when motion was detected and the control panel had "VCR style functions" [8]. Intended to be swapped out for data collection, two 80 GB hard drives were included in the system, with an option to upgrade for a maximum of 250 GB capacity (+$800). In comparison, this research outlined a prototype that offered 500 GB, allowing for a longer deployment period before necessary data collection as compared to the SeeMore™ [8] and Golightly [10] designs. RemoteDVR™ was a four-channel DVR, so only four cameras could be connected at one time. The prototype from this work had scalability to record eight channels on one DVR, scanning for motion in each camera feed with independent recording trigger per feed. The all-weather cameras had infrared for night recording, similar to the prototype here. An LCD screen was also offered to review video in the field, which would have been a great addition to the burrowing owl setup, but was not necessary in the scope of this research.

Of course, game or trail cameras naturally came to mind for wildlife imaging, however, as with many application-specific designs, they had their limitations [2]. The typical game camera housing was bulky, making it infeasible for the specific camera placements at the final observation site. Another hindrance was the relatively small storage space [10, 16], in comparison to the 500 GB storage space of the selected system. In addition, some game cameras had solar panels to help address the issue of swapping batteries. Some game cameras offered wireless transmission of the images, but that was not yet feasible for the El Paso site.

Trail cameras had been used briefly at the site before, but it was infeasible with the time and labor intensive commute to and between burrow sites at Rio Bosque. The batteries and data cards needed replacement every three to four days. Since it was less than the RemoteDVR™ system, the Closewatch Nest Box & Wildlife Cameras™ system was chosen as a maximum budget for the user-built prototype presented in this research. A list of some comparable products are provided in Table I.

TABLE I
COMPARABLE PRODUCTS

Product	Description	Cost (USD)
Closewatch Nest Box & Wildlife Cameras™ UHR-IR	three cameras and two recording drives*(ships from UK)*	$1700
Raptor™ Cellular Camera System	Three cameras with individual recording drives	$3000
Encounter™ 5MP HD IR Action Camera	Three cameras with individual recording drives	$450
Swann™ DVR8-2550 with P550 cameras	Set of four cameras with central recording drive	$400

3.3.2 Alternative User-Built Approaches

While trail cameras were frequently used for other wildlife imaging applications, this research provided unique challenges. In addition, researchers have grown more curious about the application of DVR systems because of the larger storage space, improved image quality, and video archiving [2]. As surveillance systems grow in popularity for security use, there is an incredible assortment of other closed-circuit television (CCTV) DVRs and cameras with a number of features [2].

The design in [17] essentially recreated the DVR using a low-power customizable processing board for video acquisition and compression. Another interesting approach could have been to use a distributed smart camera network [18] in which processing is done on an embedded board at the camera and transmitted to a central location. While these designs had potential, the current research was already being conducted prior to discovery of this design. This project took a centralized approach, where the processing and storage was handled by the DVR unit instead of at the camera, unlike distributed smart camera networks.

3.3.3 Digital Video Recording Systems Overview

In 2009, Brown [6] provided a concise comparison of video technology available for wildlife monitoring, highlighting the advantages and disadvantages of the different features. For examples of applying this technology, the reader is directed to [2] for a well-organized collection of case studies cogent to nest monitoring in a variety of settings and project scopes. Cox, in 2012, discussed the rising trend toward digital equipment as opposed to comparable analog equipment [2].

Essentially, the digital video surveillance system consisted of cameras and a DVR capable of compressing the video with time/date information and allowed viewing the contents on a local display monitor [2]. The centralized design, in the sense that the images from the cameras were all sent back to the one host DVR, was best for the prototypes at Rio Bosque so that the biologists would not have to collect the memory drives from each camera location.

The DVR and cameras could be described of as a sensor system, containing: a sensor module, a controller (software, CPU, memory, wireless module), and power. A sensor essentially converts one type of energy into a usable electrical signal for information transfer. For example, a soil moisture sensor might use a voltage level to represent the moisture level at the probe and the system would interpret that into meaningful data that is recognized as a moisture reading [19, 20, 21]. In this setup, the cameras were visual sensors and the DVR was a controller that interpreted, stored, and displayed that information in a meaningful way. Power was included in the sensor system as a common dependence among all of the components.

3.3.4 Selected Recording System and Off-Grid Equipment

An eight-channel DVR and camera surveillance kit (Swann™ DVR8-2550 and four P550 cameras) [22] was selected for this research, from among the many camera solutions for wildlife monitoring scenarios. The DVR functionality offered a simple menu system for navigating through the features, keeping the technology learning curve lower. Although the design only needed three cameras, an option to hook up two burrows systems at the same DVR (if they can be physically close enough to run the cables for video and power) was provided.

Fig. 3.4 shows the selected system that met all of the design specifications identified, did not require overseas shipping, and cost 66% less than the originally suggested Closewatch Nest Box & Wildlife Cameras™ system. The Swann™ system offered a central recording box for up to eight cameras, reducing equipment bulk on site and manual labor associated with data retrieval. In terms of storage, the DVR executed

H.264 standard compression which maximized storage capacity on the hard drive. The I/O capabilities of the DVR were suitable for this project, including: BNC connections for the cameras, VGA for video output to a monitor, USB port for computer mouse, USB port for backing up files to flash drive, and LAN. The video signal type was NTSC and recorded at a resolution of 352x240 (CIF).

Fig. 3.4. Swann™ 8-Channel DVR with 4 Cameras

High quality IR cameras intended for outdoor use were selected and, with infrared enabled, the cameras required a minimum illumination of zero lux, which was necessary for the den camera especially. Dome cameras were available, as well as pan-tilt-zoom (PTZ) cameras. However, these features would not necessarily improve the results for this application, so costs were minimized by using a traditional bullet camera. The utilized system came with PRO-550 cameras shown in Fig. 3.5, offered a 62 degree viewing angle and 420 TV lines of video quality [22].

Fig. 3.5. Swann™ PRO-550 infrared cameras

With the set-it-and-forget-it approach, a sturdy equipment box needed to withstand the elements, be lockable, and made of hard plastic to run the cables through a small hole in the side. Pelican™ cases are used for all-weather transportation of

expensive equipment, but it was also found to be the right shape, size, and provided functionality appropriate for the scope of this project. Air space inside the equipment box was allowed for air movement around the DVR and batteries. Similar to the design in [2], the selected Pelican™ case was large enough to house the hefty battery bank. Quick-drying silicone sealant worked well for sealing small gaps around the junction box entrance to the Pelican™ case.

The batteries selected for this project were the Lifeline® deep cycle marine sealed lead acid batteries, rated maintenance-free. The solar panels used for this project were 100 W polycrystalline photovoltaic solar panels (100 W maximum power, 17.4 V maximum power voltage Vpm, 5.75 A maximum power current Imp). Purchased as a kit, the solar panels came with an appropriate 30 A charge controller, cabling, and weatherproof MC4 connectors.

3.3.5 Solar Panel Mount

Originally, the solar panel mount was designed and constructed alongside the RET team, made of slotted angle iron and galvanized bolts (see Fig. 3.6 and Fig. 3.7). The panels were affixed using large t-shaped gate hinges. The panels required a sturdy frame facing south, and placed at the latitude angle [23]. This approximate 32 degree angle was harder to accomplish with the angle iron because the pieces had to be cut to size, and sometimes the slots did not line up without modification.

Fig. 3.6. Side views without panels and close up of mount

Fig. 3.7. Front view of the frame and rear view with equipment

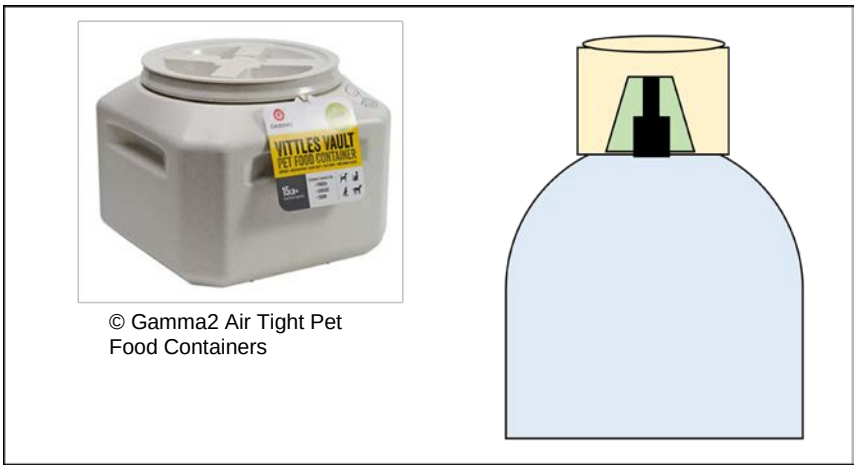
Some homemade smaller-scale solar panel mounts made of black metal piping inspired a way to minimize the angle-iron frame. Fig. 3.8 shows the revised design that was simpler to install, required fewer tools, provided more room for the equipment box below, allowed modifying the angle of the panels on-site, and still was a sturdy mount for the panels without increasing expense of the prototype. The frame made of 1-1/4" galvanized threaded pipe and tees worked well, especially when the vertical legs of the frame were secured in 5-gallon buckets of concrete, and buried the depth of the bucket. U-bolts secured the solar panels to the horizontal rail, and pipe wrenches were used to tighten the threaded pipe fittings.

With the threaded pipe design, the U-bolts could be loosened to rotate the panels around the horizontal axis, allowing easy setting of the angle on site. The panels were bolted together to prevent gapping, and to help reduce the effect of wind blowing the back of the panels hard enough to rotate them forward around the pole. For additional support, the lower corners of the outer panels were bolted to a piece of the angle iron in the ground. This design was a drastic improvement to the angle iron frame in terms of ease of installation and customization.

Fig. 3.8. Threaded-pipe frame

3.3.6 Camera Mounts and Access Tunnels

For minimal change to the original den access design, a camera box could have been inserted under the weighted inner bucket, resting on the platform to the den. However, the number of pieces was reduced and better protection from the elements was provided by instead utilizing a single screw-top airtight plastic storage bin, repurposed to house the platform and camera box inside (see Fig. 3.9). The Vittles Vault™ 15 4.7 gallon pet food storage bins (see Fig. 3.9) worked well, and at 12"x 12"x 9.8" were not excessively large nor too small for den access.



© Gamma2 Air Tight Pet Food Containers

Fig 3.9. Example bin and a den access diagram

The tunnel camera mount did not interfere with the tunnel layout, allowing organisms to enter the original tunnels from outside. To add a camera at the elbow, the 4" PVC elbow fitting was replaced with a 4" PCV tee fitting.

Although the camera could be quickly secured to the PVC tee fitting at the tunnel elbow, maintenance needed to be considered. Sealing the cameras into the fitting and buried with the tunnels would require digging up for cleaning, replacing, and repositioning. Therefore, the screw-top bin design was modified for the tunnel elbows utilizing a taller screw-top bin (Vittles Vault™ 80, 14"x 14"x 28") with a camera mounted horizontally to watch down the tunnel entrance. To avoid making a full 4" hole in the tunnel access bins for the PVC tunnel to enter around the camera, a Fernco™ 4"x2" DWV flexible PVC coupling (shown in Fig. 3.10) fit onto the PVC tunnel, converting it to a 2" opening through which the camera face could peer into the den, similar to the plywood platform above the den. Weatherproofing tape lined the camera face to snugly fit against the bin, and then the ring was hand-tightened to help prevent organisms from trying to live with the camera instead of in front of it. In the side near the top of each

access bin was a hole through which to feed the cables in a 2" PVC or conduit to the equipment box.

Fig. 3.10. Flexible PVC coupling for the tunnel cameras

The final layout for the burrow was a total of 28" deep; from the top of the above-ground access bins to the bottom of the den and tunnel floor (see Fig. 3.11 and Fig. 3.12). The den was 17" in height with a 19" diameter den floor. At the elbows and den, the screw-top lids were 14" and 10" in diameter, respectively.

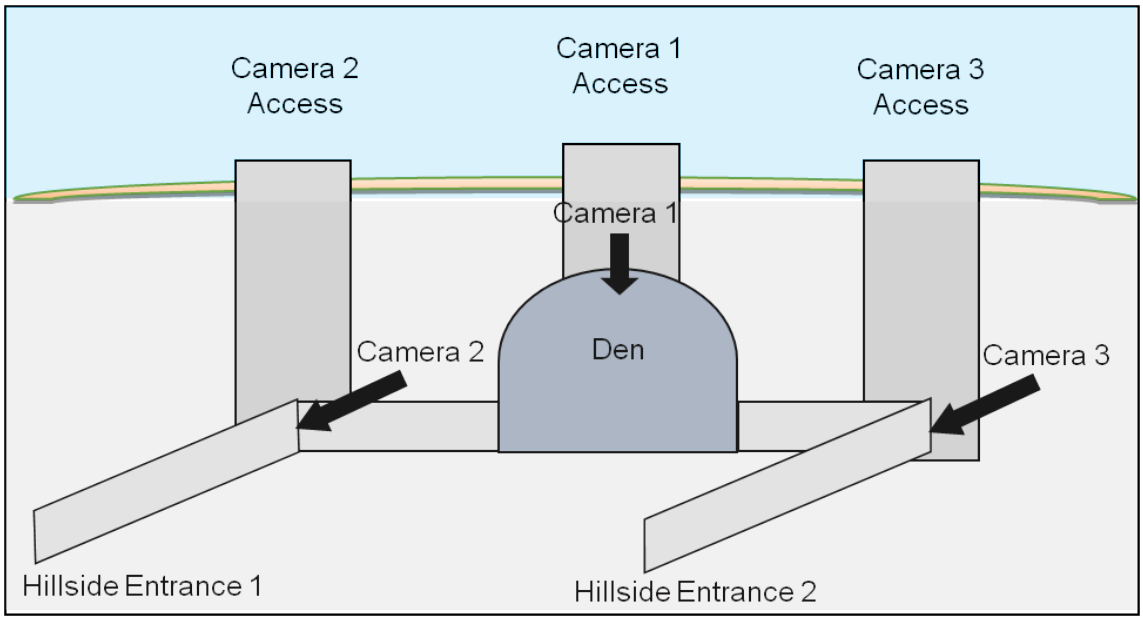


Fig. 3.11. Burrow layout at Rio Bosque with cameras

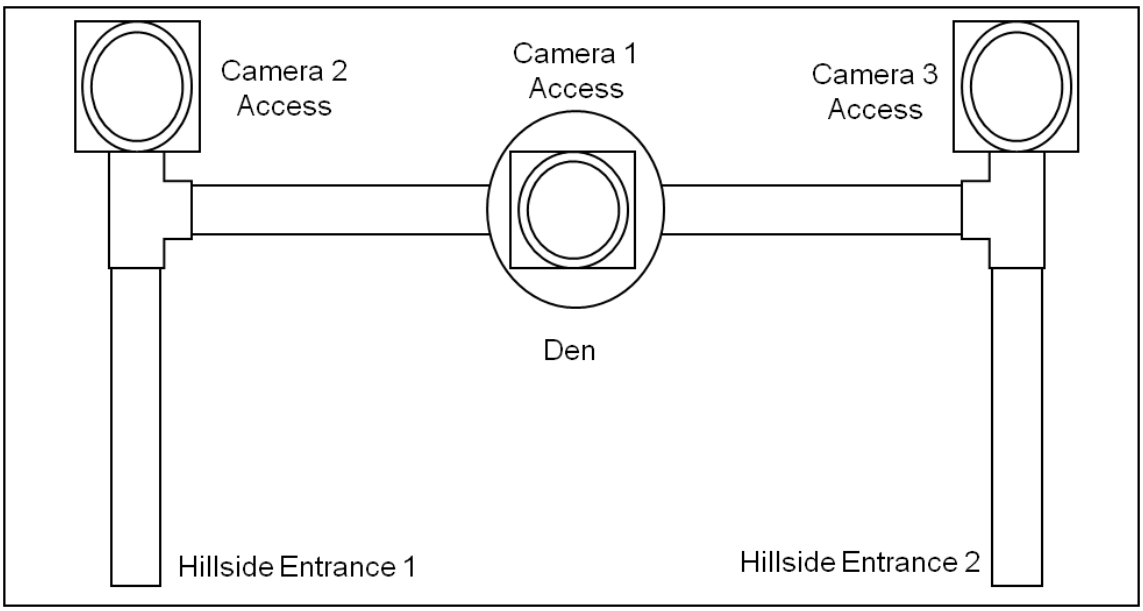


Fig. 3.12. Top view of the burrow layout

There needed to be a stable and breathable way to mount the overhead den camera and the tunnel cameras in the access bins. A 6" round polyolefin outdoor atrium grates (see Fig. 3.13) provided the height, stability, and breathability desired for the den camera. For consistency, 6" atrium grates were laid horizontally for the elbow cameras. A bolt and wood brace kept the round grate from rolling. Inexpensive hard plastic irrigation tubing was cut into 3/4" spacers and ties to lower and secure the camera to peer through the platform into the den.

Fig. 3.13. Atrium grate used as camera mount

An opening at least 8" diameter was needed in the bottom of the den access bin to allow the biologists to reach the fledglings for banding. The platform was a section of pressure-treated plywood about 1/2" thickness, cut to cover the large opening at the bottom of the den access bin. For the platform to cover the larger opening into the den, it would not simply fit through the circular screw-top opening. A simple solution was to cut the platform in half, and secure with hinges so that it could be folded to insert/remove for den access. A hole saw attachment on a handheld power drill was used to cut the 2" hole for the camera to fit through the center of the platform. From inside the burrow, the birds could see the camera face fitted flush into the platform.

3.3.7 Cost Overview

The monitoring station developed through this work met specifications, and was more cost effective than the referenced equipment quote. The cost of the on-grid four camera and two DVR system from Closewatch Nest Box & Wildlife Cameras™ was $1693 USD (see Table II), not including overseas shipping and professional installation. The cost of the DVR and camera system selected in this research was approximately $400 USD (see Table III).

TABLE II
PARTS LIST OF COMPARABLE RECORDING SYSTEM

Description	Quantity	Total Cost (USD)
Closewatch Nest Box & Wildlife Cameras™ Super UHR IR Wildlife Camera Product code: WCVF90SUHR	4	1022
Two-Channel Mini Digital Recorder, up to 32GB Product code: 2CDVR01	2	671
Recording System and Camera Total		$1693

TABLE III
PARTS LIST OF SELECTED RECORDING SYSTEM

Description	Quantity	Total Cost (USD)
Swann™ SWDVK-825504 eight-channel DVR & four cameras	1	400
Recording system and camera Total		$400

Taking the DVR and cameras off-grid and installing a new access system placed the total expense per prototype at $1821.47 USD (see Table IV and Appendix B). The cost for taking the comparable Closewatch Nest Box & Wildlife Cameras™ off-grid and installing the cameras in the same manner would have been $3114.47 USD.

TABLE IV
COST OF THE PROTOTYPE AT RIO BOSQUE

Item totals	Cost (USD)
Recording system and cameras	400
Solar panels, charge controller, batteries	1005
Solar panel mount	164.58
Camera mounts and access bins	251.89
Total	$1821.47

3.4 Preliminary Equipment Study and Power Considerations

The scenario at Rio Bosque drove the system, though other capabilities of the equipment were explored. The DVR was configured and contents reviewed via VGA monitor display, and local and remote viewing was established for simulation.

Fig. 3.14 outlines the DVR's default naming scheme, with (a) Channel ID, (b) Yr/Mo/Day, (c) Pack Start Time, (d) Pack End Time, (e) File Type H.264.

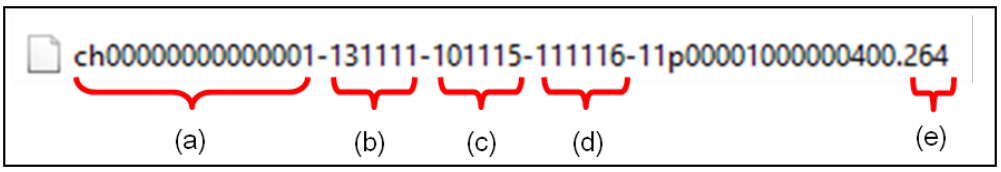


Fig. 3.14. DVR file naming scheme

As can be seen from Fig. 3.15, a camera mounted on the author's home patio directed at a birdhouse for initial observation. The video and power cables for the camera were run from outside to the DVR indoors.

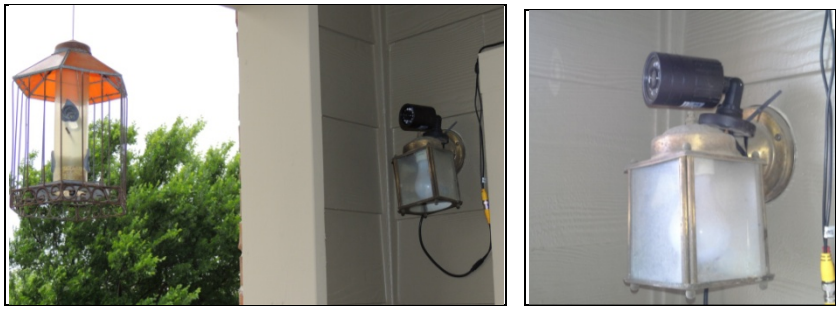


Fig. 3.15. Outdoor camera positioned at a bird feeder

Connecting the DVR to the monitor using VGA displayed the live video feed and allowed DVR navigation (see Fig. 3.16). With the system configured to record upon motion detection, unnecessary footage was captured of the bird house swinging and vegetation swaying in the wind. The automatic reboot function of the DVR was observed and showed that the motion record configurations were preserved upon sudden power loss and reboot.

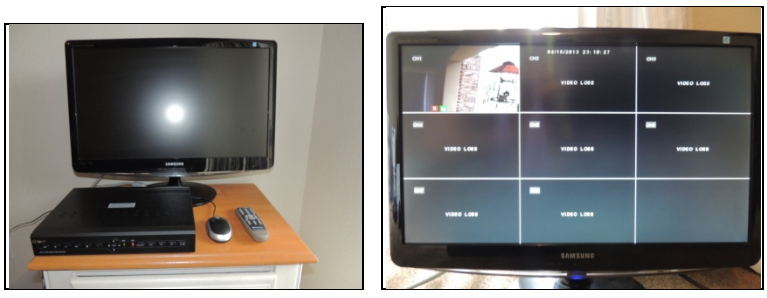


Fig. 3.16. Home setup and DVR display

3.4.1 H.264 Compression for Video Storage

Using the H.264 coding standard, the selected DVR unit compressed the video and saved the compressed files to the internal hard disk drive. The H.264 standardization provided higher rate-distortion efficiency when compared to other existing video coding standards, while offering better compression performance for both conversational and non-conversational video communication [24, 25]. This meant that the DVR was more space efficient when storing the video files and also yielded less data volume to transfer per hourly video segment. While the video coding layer of H.264 was built upon concepts from hybrid block-based motion-compensation, there are several distinguishable improvements to the H.264 design outline as discussed in 2003 by Wiegand in [25].

3.4.2 Motion Detection

Events that could trigger a shift in the DVR motion record behavior were considered to describe the relationship between states. Movement (or change between frames in the video) was one of the most obvious events that triggered a recording response. The motion sensitivity was important to ensure only information-rich video was recorded, helping to preserve disk space and energy use. Consider if a bird ruffles its feathers in a burst of movement, and then remains stationary. That movement event, and perhaps the following minutes of inactivity, might be considered irrelevant for a particular research scope and the storage space could remain available for more meaningful data. However, movement such as the bird entering/exiting the burrow or feeding the offspring would be above threshold and should trigger recording. A sample

state transition diagram depicting this series is provided in Fig. 3.17, where '0' represents movement below threshold and '1' is movement above the threshold. The DVR records in the Active state.

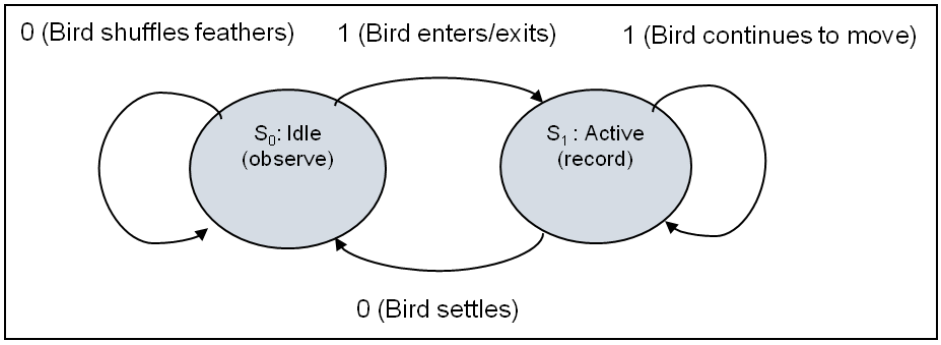


Fig. 3.17. Simple state diagram for motion record

The motion detection for this surveillance system was done by the DVR unit using digital processing, instead of a passive infrared (PIR) sensor located at the camera similar to most game camera designs [6]. The cameras were constantly sending feed to the DVR, where the DVR analyzed the input and determined when to record based on user configurations. Although the specific motion-detection algorithm for the selected DVR is unknown by this author, it appeared the decision was completed by frame-to-frame comparison of the input feed from each channel input to the DVR. Unfortunately, that meant the cameras ran continuously, thus wasting power. Motion detected on a channel only recorded that channel, not all channels connected to the DVR, which saved storage space for more meaningful data.

Setting the sensitivity and the region of interest (ROI) in the channel frame was a feature of the selected DVR. The ROI was configured when the cameras were installed, and was not intended to change after setting, which introduced a chance of error in detecting meaningful movement. When using stationary camera mounts, for example, a

short animal might pass below the camera's field of vision or DVR's ROI, avoiding motion triggered video record.

3.4.3 Remote Access to the DVR

While having the stand alone system suited the original project description, options for viewing the settings and contents of the DVR over the internet were explored. Having access to the data off-site would be valuable beyond simply viewing live-streaming data from the DVR, because the data would be available for download to a personal computer and recording configurations could be altered. The ideal case would be for a transmitter to send the DVR signal to a router connected at a host computer.

Bandwidth was important with the LAN connection, but became even more so with wireless communications. To aid in this, there needed to be high compression efficiency (i.e. the H.264 standard) because of the generally low bit-rates selected by users to avoid fees [24]. In 2003 Stockhammer [24] described four types of service classes for video applications: conversational, streaming, interactive, and background traffic. With the full functionality of remote access to the DVR, then the applicable traffic classes could be: streaming, interactive, and background [24]. The video feed was streaming when connected to the DVR, but the main treasure was remote access to the stored videos as more of a background service class [24].

During the home setup, a successful local connection was established via LAN to a home router with administrative access, allowing remote login to the DVR on a shared network. With the router and DVR following DHCP, the local IP address of the router

could be typed into an internet browser to communicate with the DVR from on the shared network. Through the internet browser, the stored files on the DVR can be viewed and downloaded–ideally eliminating exhaustive trips to the field for configuring the DVR and collecting data. The wiring diagram is provided in Fig. 3.18, using a shared internet connection via the router.

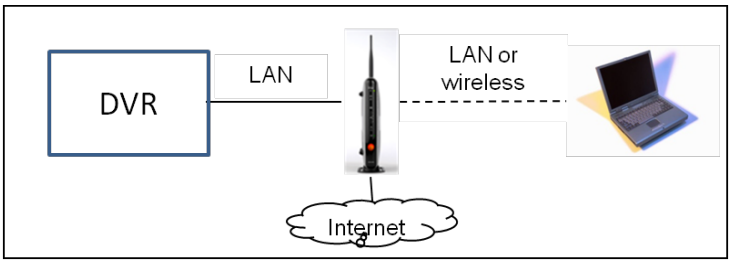


Fig. 3.18. Local viewing scenario (shared network)

The router used for initial testing was the Verizon™ FiOS ActionTec™ MI424WR wireless router [26] with the router's public IP address being 96.226.56.104. On the shared network, the local IP address for the DVR on was 192.168.1.235 assigned by the primary router at the 192.168.1.1 gateway. The Web Port was 40085 (set on the DVR), which was the port to communicate with the DVR over the internet locally. To connect remotely to the DVR in a local network configuration the IP address was 192.168.1.235:40085. Accessing this Web Port brought up the Swann™ DVR login screen, where the Media Port was 49002 (set by the DVR). Fig. 3.19 shows the login screen that appeared in the browser, with live viewing mode as the default view.

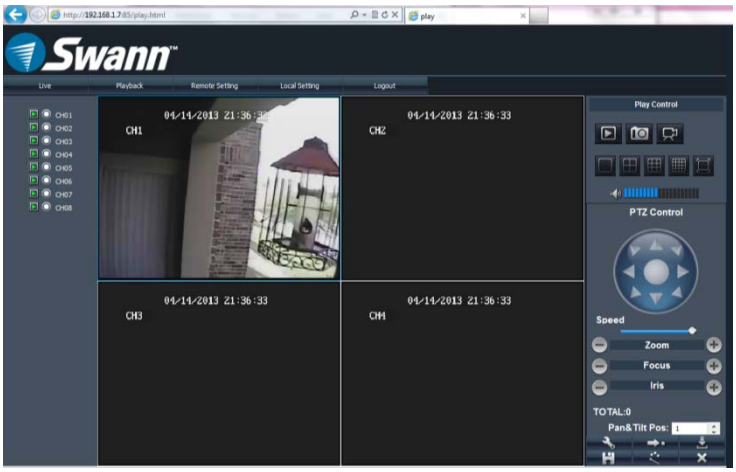


Fig. 3.19. Swann™ live viewing

The network configurations page pictured in Fig. 3.20 shows the settings for communicating with the DVR over the network. Notice that the Media Port and Mobile Port are also listed.

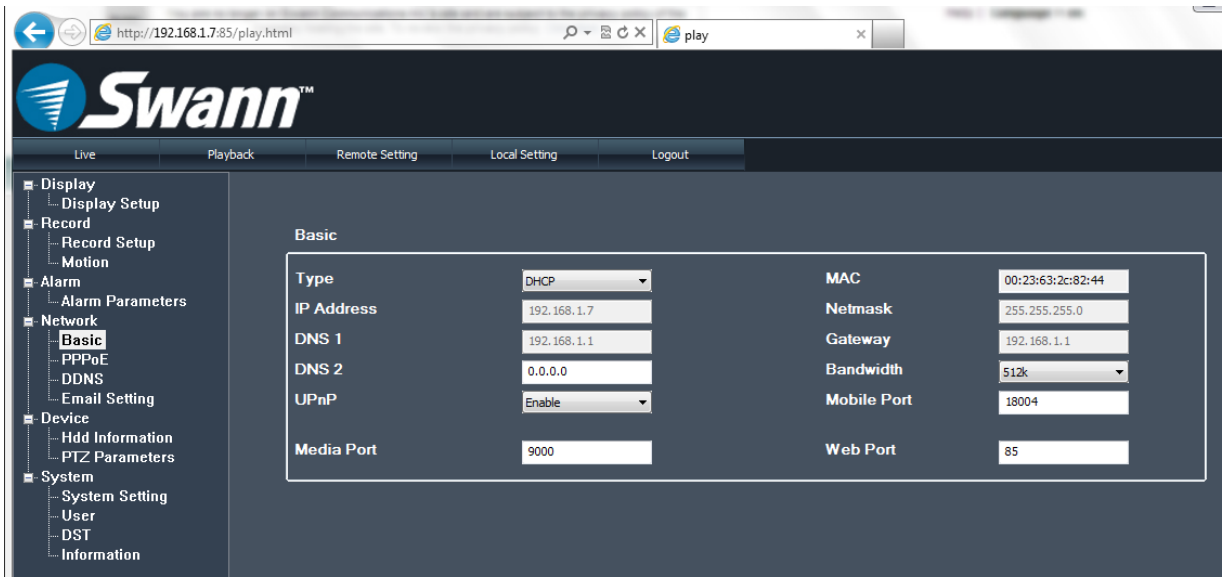


Fig. 3.20. Swann™ network configurations

While viewing the feed locally on a shared network was beneficial, it was better to have remote connectivity to the DVR from outside of the network. To better explain the setup, Fig. 3.21 shows the DVR connected via LAN to Network A, while the user

accesses the DVR on a laptop connected to a router on Network B. Both routers must be connected to the internet.

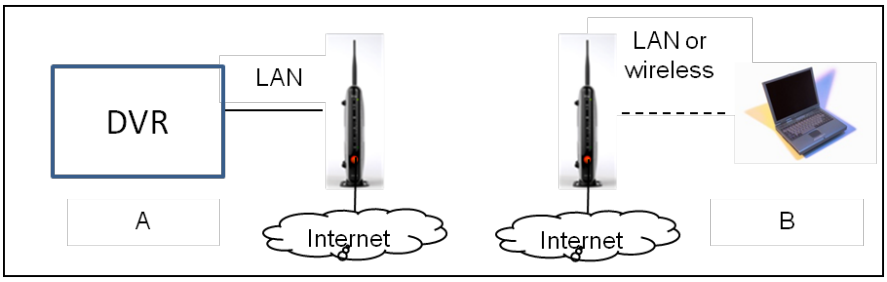


Fig. 3.21. Remote viewing scenario (outside the network)

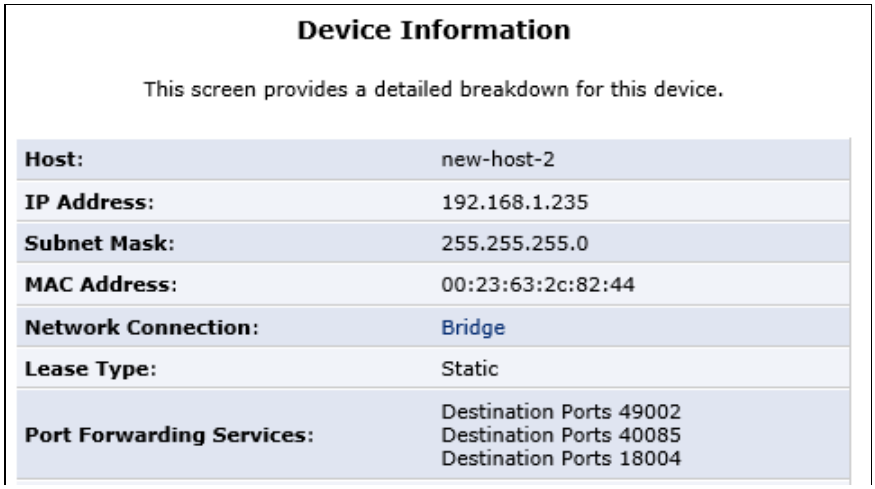
To do this, the public IP address for the router was needed (96.226.56.104), as well as the desired ports from the DVR for accessing certain data. The Web Port 40085 was necessary for connecting to the DVR over the web browser, the Media Port 49002 for accessing media on the DVR, and Mobile Port 18004 for viewing over the cellular network using a mobile phone. Since global access required logging into the router via the public IP instead of the DVR specifically, the relevant ports from the DVR's local connection were forwarded to the router. Otherwise, the local DVR ports were not visible nor accessible via the router on the public IP.

Port forwarding was completed in the firewall settings section of the router configurations screen following [26], after logging into the router from the public IP address. Fig. 3.22 shows a screen capture of the ports added to port forwarding on the router, note the device IP was that for the DVR 192.168.1.235.

☑ 192.168.1.235	Destination Ports 49002 TCP Any -> 49002	All Broadband Devices	Active	☐
☑ 192.168.1.235	Destination Ports 40085 TCP Any -> 40085	All Broadband Devices	Active	☐
☑ 192.168.1.235	Destination Ports 18004 TCP Any -> 18004	All Broadband Devices	Active	☐

Fig. 3.22. Port forwarding in firewall settings

Fig. 3.23 shows the device information screen for the DVR (192.168.1.235) with the updated port forwarding services for Media Port 49002, Web Port 40085, and Mobile Port 18004.



Device Information

This screen provides a detailed breakdown for this device.

Host:	new-host-2
IP Address:	192.168.1.235
Subnet Mask:	255.255.255.0
MAC Address:	00:23:63:2c:82:44
Network Connection:	Bridge
Lease Type:	Static
Port Forwarding Services:	Destination Ports 49002 Destination Ports 40085 Destination Ports 18004

Fig. 3.23. DVR device information on router configurations

Once the ports were forwarded, the DVR could be accessed from outside the network using the router's public IP and the DVR Web Port. The Swann™ DVR login screen was accessed at the global address 96.226.56.104:40085 and entering the Media Port, user name, and password allowed access to the DVR contents and configurations.

In addition, forwarding the Mobile Port enabled mobile viewing through the SwannView™ smartphone app. Incorporating wireless access could allow biologists to check for site activity even while away from their computer. Multiple cameras could be displayed on a web browser or a mobile app for iOS™ and Android™ [22]. Once configured, the camera feed was streaming and archived files were available. Fig. 3.24 shows the configuration settings referencing the appropriate IP (local or public) and the

Mobile Port 18004, with the DVR login information, and a mobile view (using an Android™ phone) of the DVR accessed on the global network.

Fig. 3.24. Swann™ Remote (mobile) viewing

3.4.4 Intro to Going Off-Grid with Solar Panels

A growing technology in the field of alternative energy sources for environmental monitoring is the use of photovoltaic (PV) cells, modules and arrays [19]. PVs convert solar radiation into electrical power for use by a system load. In the PV unit, the material absorbs photons from light and releases electrons. Capturing these free electrons generates electrical current for use as electrical power. PV cells can be combined to create a PV module and several PV modules can be combined to create a PV array, or solar panel array.

However, limitations exist with solar panels that introduce inefficiencies for electrical power generation. Among them include the position and angle of the sun's rays to the surface of the PV unit affecting efficiency [19]. As the position of the sun changes with respect to the PV surface and as the day progresses, the amount of voltage and electrical current supplied fluctuates. Developments in technology include

several methods to combat the limitations and increase efficiencies of the PV units, such as Maximum Power Point Tracking (MPPT) systems [19].

The selected Swann™ DVR and cameras operated at 12 V DC, typically delivered by the accompanying power supply. That power supply would traditionally plug into a standard 120 V AC power outlet on-grid, and convert the output to 12 V DC for the devices. Some designs in the literature that used a 12 V battery included a power inverter to preserve the use of the standard power supply, while others like [10] kept the system in DC from the batteries. Since the power was already in DC from the charge controller to the load, it was excessive to use a DC-AC power inverter to utilize the original power supply.

Deep-cycle sealed lead acid batteries are commonly used for outdoor applications, such as that for this research, because of their high dependability, stability, and symptoms of nearing end of lifespan [2, 21]. Nickel Cadmium tends to deplete faster than lead-acid and often requires that the battery be completely drained before recharging for longer lifespan [21]. The Lifeline® manual [27] recommended to increase the size of the selected battery by 20% to account for inherent inefficiencies, and to use an automatic charge controller rated at least .2*C, where C is the rated Ahr capacity of the battery. A proper load cutoff was also necessary to ensure that the system was not depleting too much of the battery charge. Preventing such deep large depth of discharge (DOD) would help to maintain the lifespan of the battery [27].

3.4.5 Sizing the Solar Panels and Battery Backup

Essentially, there were three major steps and corresponding calculations to consider for taking the system off-grid: (1) power consumption of the load, (2) battery

capacity, and (3) solar panel output [21]. Prior to sizing an energy source, the power consumption of the DVR and cameras needed to be taken into account. The first prototype was built upon the estimated power consumption as provided by the manufacturer. As quoted by the manufacturer, the current draw of the DVR was 2.0 A and the set of four cameras was 2.0 A, totaling 4.0 A required by this 12 V DC load. It was discovered, in testing the first prototype, that the actual current draw was considerably less than specified (see Table V). Thus for the second prototype the actual current draw was used.

TABLE V
POWER CONSUMPTION REFERENCE POINTS

Device	Current (Amps)
DVR (quoted)	2
4-cameras (quoted)	2
DVR (actual)	0.69
4-P550 Camera (light)	0.44
4-P550 Camera (dark-IR)	0.67

Since burrowing owls can be active all day and night [1], the power consumption had to be calculated assuming motion 24 hours per day. To calculate: power consumption in Whrs/day = (device voltage)*(device current)*(hrs active/day). Using the original quoted values, the consumption was at 1152 Whrs/day. In fact the equipment used much less than quoted, yielding a power consumption of 391.7 Whrs/day (see Table VI).

TABLE VI
POWER CONSUMPTION (Whrs/day) FOR BASIC OFF-GRID

Scenario	Hours Active Daily	Number of IR Cameras		
		1	4	8
Quoted	24	720	1152	1728
Basic Off-Grid	24	246.96	391.68	584.64

Step two included determination of the associated battery capacity for load support. To calculate: capacity in Ahrs = (# days backup)*(device current)*(hrs active/day), then +20% for inefficiencies. Using only one backup day yielded a battery capacity of 39.168 Ahrs (see Table VII).

TABLE VII
BATTERY CAPACITY (Ahrs) FOR BASIC OFF-GRID

Scenario	Hours Active Daily	Number of IR Cameras		
		1	4	8
Quoted	24	72	115.2	172.8
Basic Off-Grid (24/7)	24	24.696	39.168	58.464

The third step and final calculation was the corresponding solar panel output to support the load (DVR and cameras) and recharge the battery bank size identified in Table VII. In [21] the number of days to recharge was set to equal the number of backup days to 50% DOD, one day in this application. To calculate: daily solar panel output in Ahrs/day = [(hrs active/day)*(device current)+(battery capacity)]/(# days to recharge). The basic off-grid setup to power the DVR and four cameras 24 hrs/day would require 71.8 Ahrs/day of solar panel output. Table VIII shows the results.

TABLE VIII
SOLAR PANEL OUTPUT (Ahrs/day) FOR BASIC -OFF-GRID

Scenario	Hours Active Daily	Number of IR Cameras		
		1	4	8
Quoted	24	132	211.2	316.8
Basic Off-Grid (24/7)	24	45.276	71.808	107.184

For reference, the available off-grid solar panel kits and corresponding estimated daily output from the Windy Nation™ product descriptions [28], updated 2013, is provided in Table IX. In personal communication with Technical Support on 11/3/2103, the representative stated as reference that each 100 W would provide approximately 400 Whr/day of power and suggested sizing the solar panel array so that the maximum required solar panel output would be near the lower estimated output value quoted (see Table IX), due to inherent inefficiencies of solar panels and season changes in the angle the sunlight hits the panel surface. For example, the calculated 71.8 Ahrs/day would suggest the need for a 300 W system (see Table IX).

TABLE IX
SOLAR PANEL OUTPUT PER DAY (Ahrs/day)

Size of Solar Panel Array	Ahr/day
400W	100-200
300W	75-150
200W	50-100
100W	25-50

Based on these calculations, questions were posed, such as: (1) what would be the difference in solar panel output per day required for a system with one DVR and four cameras using among a 200 Ahr, 100 Ahr, and 60 Ahr battery bank; and (2) what would be the solar panel output per day required for a system with two DVRs and eight

cameras using the 200 Ahr battery bank compared to the 100 Ahr battery bank? The resulting values were: 232.64 Ahrs/day, 132.64 Ahrs/day, 92 Ahrs/day, 265.28 Ahrs/day, and 165 Ahrs/day, respectively.

3.4.6 Wild Watch and Power Management with RET

The functionality of the video and power equipment was verified in a lab setting, and the feasibility for this application was examined at a local outdoor test site, IDB. A proposal was provided for IDB requesting they host the outdoor equipment study in 2013 and accepted prior to installing equipment.

In the summer of 2013, together with four local high and middle school teachers in the RET program at UNT, a mock burrow and an off-grid video station prototype was constructed. Starting on-grid in the field allowed time to begin collecting data, while providing time for off-grid preparations. Then moving off-grid, the system comprised of one DVR, four cameras, two 100 Ahr batteries, 30 A charge controller, and a 300 W solar array.

There were inline AC power meters that would suffice to study the energy demand of the system, though this was a good opportunity to give the RET team hands-on experience using a digital ammeter for current measurements under several likely scenarios potentially impacting the DVR and camera power consumption. An identical spliced power cable and female port shown in Fig. 3.25 helped get these inline current measurements. A difference in power consumption for the four cameras was witnessed between a dark versus a well-lit space (0.67 A and 0.44 A). However, the recording

settings nor number of cameras actively recording on the DVR changed the power consumption of the DVR unit.

Fig. 3.25. Spliced power cable and port

Cameras were deployed aboveground in two L-shaped tunnels, a burrow [1], and a birdhouse. Fig. 3.26 is a collection of pictures from installation day of the 300 W IDB system. Camouflage spray paint made for plastics came in a sandy color, which disguised the equipment box in both the local and final sites.

Fig. 3.26. RET install at IDB

It was found that the cameras operated in an always-on configuration, which was not ideal for this off-grid application but had to work since they were already purchased. The backup process from DVR to USB storage drive took: 105 seconds for 195.4 MB, and 600 seconds for 1176.9 MB. The outdoor test at IDB with the RET team detected bugs and mice in the burrows (see Fig. 3.27), after monitoring continuously over three deployments spanning several days each. When the quick set motion record configuration did not perform well on one of these tests, using the Scheduled Record Mode with motion detect enabled resolved this (see Fig. 3.28).

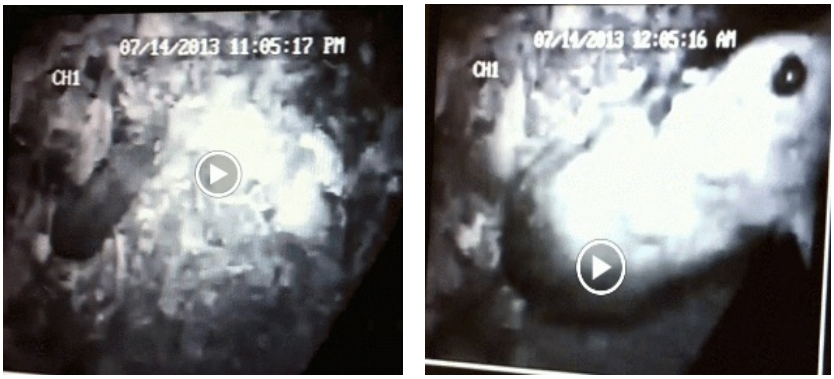


Fig. 3.27. Two different mice visited the burrow

Fig. 3.28. Screen capture of the RET field test

Upon first review, the image was out of focus, suggesting that the camera was mounted too close to the den floor. A series of den height trials, to anticipate objects in the Rio Bosque burrows, involved not only the distance from the camera to the den floor but also the clarity for nest- and owl-sized objects in the den. To resemble a nest, the object was a 5"x5"x5" box with a small owl figurine and a couple of extra chicken eggs. It was determined that 14" minimum was necessary to provide the best clarity for a nest-sized 6" tall object, yet only provided a viewable 12" diameter den floor.

One set of P640 cameras came with one of the DVR systems, as a 'free upgrade'. Lab testing showed the P550 was better than the P640 for this close-range application in the den. The P640 (the "upgraded" model) was rated for 50% longer range of night vision, suggesting that the minimum focal distance was a bit larger than that of the P550s. In Fig. 3.29 through Fig. 3.31, the images were taken in a mock den with both the P550 and the P640, adjusting the distance of objects in view to mimic what might be seen in the field burrows. Those captured with the P550 are on the left and the images on the right use the P640. Of less concern were the tunnel cameras, since they look down four feet of tunnel.

In the first row of images, the den was 17" tall den with a 5" tall nest (object was approximately 12" from the camera). Nearly the entire den floor 12"x12" was in view, as well as the walls and the tunnel entrances. The second row of images was taken in a 14" tall den with the 5" tall nest (object was approximately 9" from the camera), leaving the 12"x12" floor and the edge of the tunnel visible. Adult burrowing owls are approximately 9" tall [1], so the test object was raised to be 9" tall in the 14" den (object was approximately 5" from the camera). Using this setup, the object occupied most of

the frame, leaving little of the den floor in view. The clarity obviously reduced at closer distances, for both the P550 and the P640.

Fig. 3.29. P550 and P640 in a 17" tall den with 5" tall nest

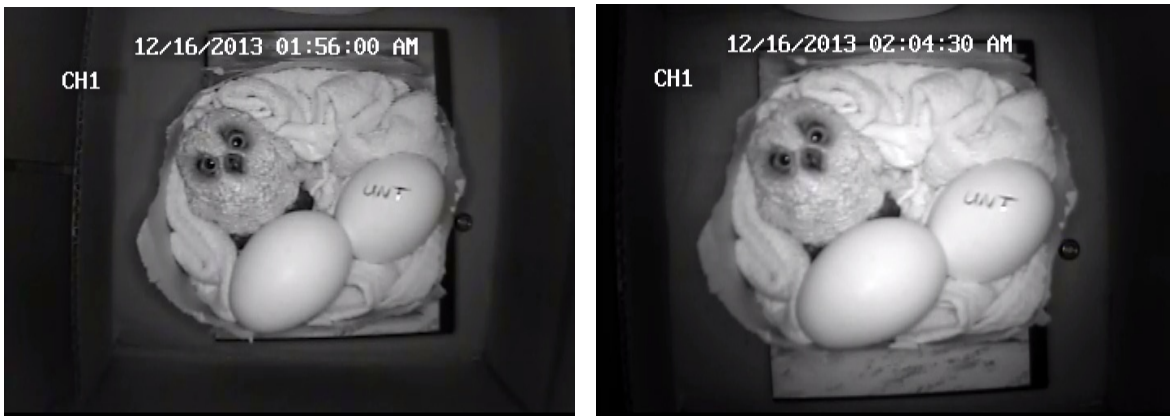


Fig. 3.30. P550 and P640 in a 14" tall den with 5" tall nest

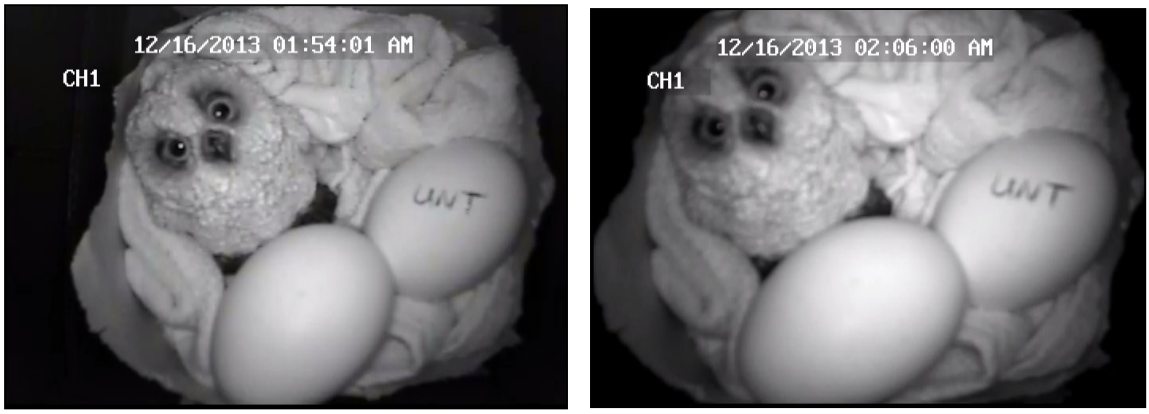


Fig. 3.31. P550 and P640 in a 14" tall den with 9" tall bird

While changing the P550 for the P640 in these home trials, the author's housecat explored the 17" burrow (see Fig. 3.32). The cat stood approximately 10" at the shoulder, placing the object approximately 7" from the camera).

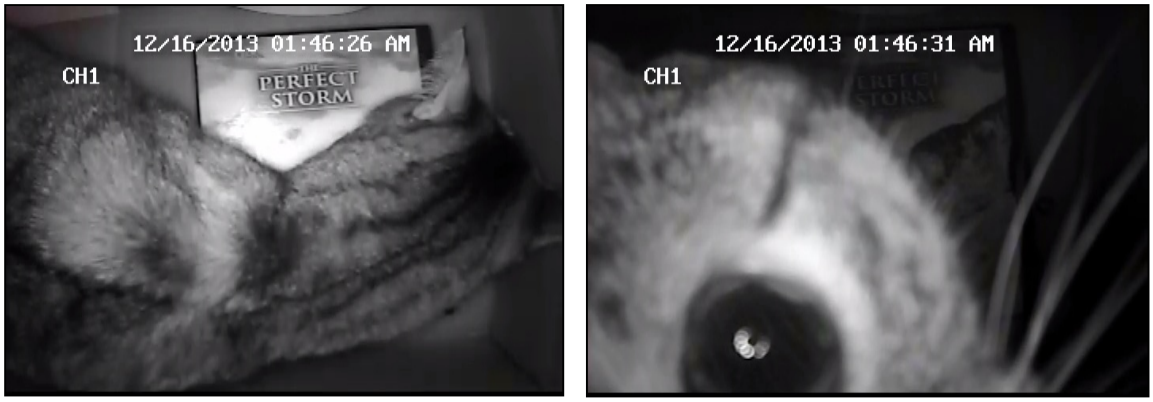


Fig. 3.32. P550 and P640 in a 17" tall den with 10" tall housecat

Now that the P550 was selected over the P640, the question arose of how much den space would be visible in the frame at the 17" tall den, depending on the diameter of the barrel used as the den housing. A P550 camera was secured to a tripod and circles drawn on butcher paper outlined the two den floor options: one 12" diameter as reference and one 19" diameter as the blue barrel used at Rio Bosque (see Fig. 3.33).

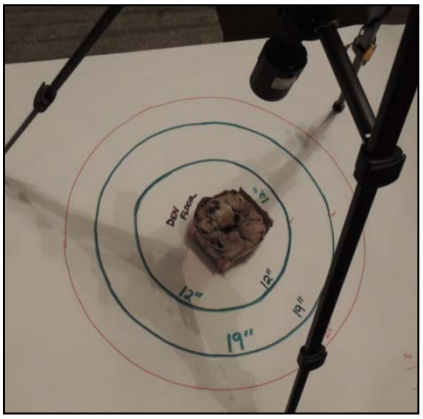


Fig. 3.33. Tripod and den floor setup

At the 14" den height, most of the 12" diameter floor space was in frame as was witnessed in the den height trials. Raising the den to 17" tall seemed to be appropriate for this study because a decent portion of the 19" diameter floor space was visible (see Fig. 3.34). Of course, the results were even better at a 19-20" den height, where a majority of the 19" floor is in view. However, that den height might prevent the biologists from reaching into all edges of the den for banding. Therefore, the research moved forward with the 17" den height in El Paso. Originally, the blue barrel design from TPWD was 13", so older burrows in need of repair would be replaced with a 17" design.

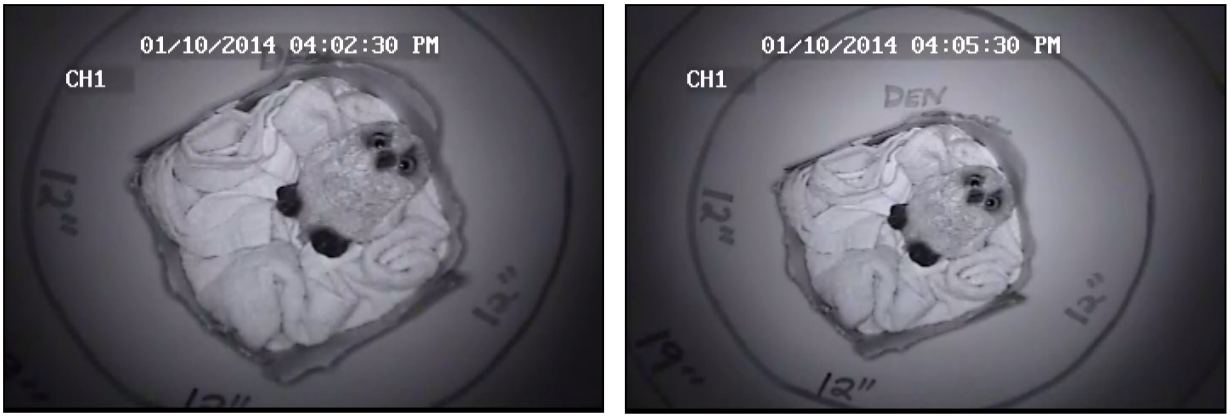


Fig. 3.34. P550 in a 14" den height and 17" den height

After taking the system off-grid with solar power, the team was challenged with identifying a means for reducing system power consumption. Due to the high energy demand of the infrared cameras and the hefty HDD, exploration of ways to minimize the power consumption was of significant importance. From a power management standpoint, the system would benefit from a motion-triggered “system wake-up” in which the video equipment would not receive power until movement occurred in the burrow, similar to using motion detection in the video to reduce excess video storage. This concept was similar to motion-triggered light switches in homes to save energy.

The "Wake-up" prototype used the Arduino™ UNO microcontroller, a passive infrared (PIR) motion sensor, 12 V DC relay, and supporting components (see Fig. 3.35). Selected for its scalability and success in sensor system applications, the Arduino™ microcontroller was a good start for the prototype with its open-source platform, lower learning curve, and versatility. The research investigated using the Arduino™ UNO microcontroller to "wake up" the system, essentially using it as a power controller based on a triggering event (motion). Calibration of the motion sensitivity was available through the Arduino™ microcontroller, ensuring the system would only wake up to record data-rich movement in the nest.

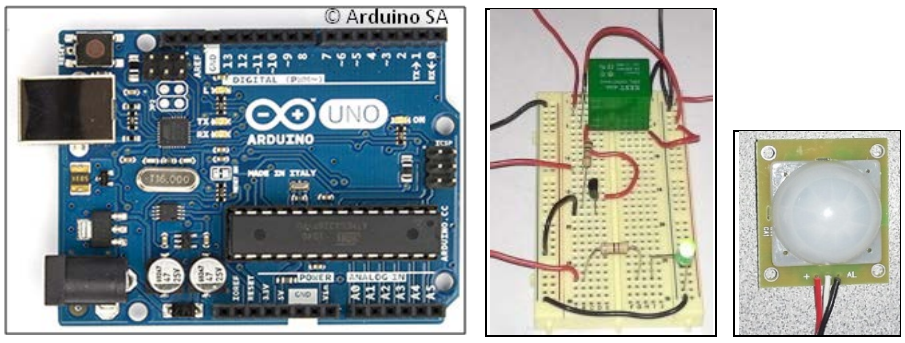


Fig. 3.35. Arduino™ UNO and prototype with PIR sensor

Initially, the Wake-up design used a relay to switch on power for the DVR and cameras when motion was detected at the PIR sensor. However, after power up the DVR took 45 seconds to boot up before being available to record video input. Therefore, the DVR was kept in an always-on configuration and the research proceeded with managing power to the cameras only. Fig. 3.36 shows a block diagram depicting a microcontroller connected to a relay that toggles power to the cameras. The dashed box represents the weatherproof equipment box.

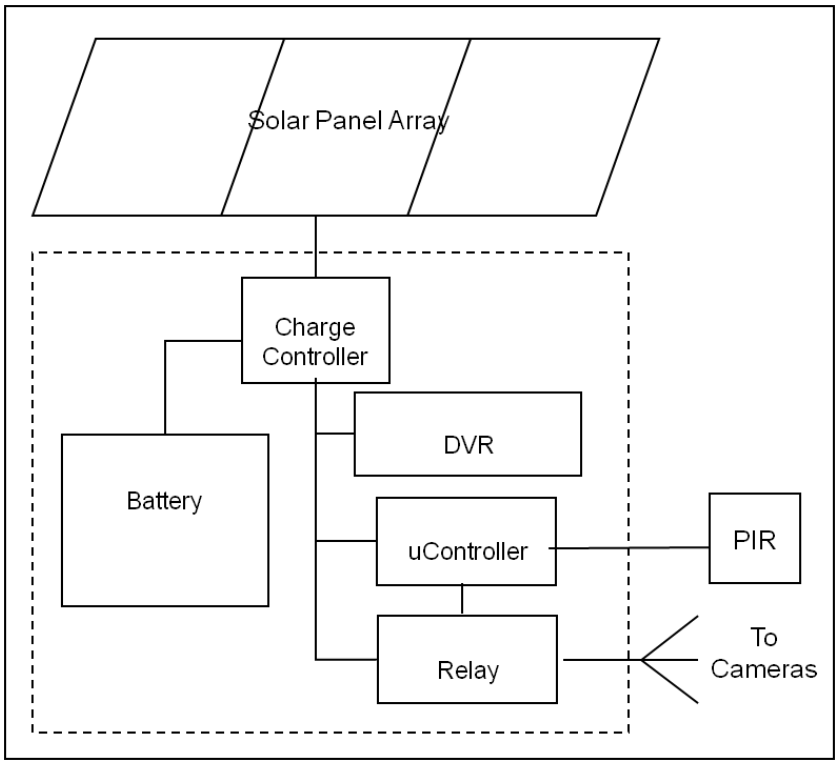


Fig. 3.36. Block diagram of the Wake-up prototype

In the preliminary “Wake-up” design (see Fig. 3.37 and Fig. 3.38), the cameras would send video to the DVR immediately upon receiving power. The RET team completed some successful testing, but the "Wake-up" prototype remains an element of continued research and could move toward a custom printed circuit board (PCB) with design files for replication. For demonstration purposes, PCBWizard™ printed circuit

board design software was used to convert the schematic into a PCB design file shown in Fig. 3.38.

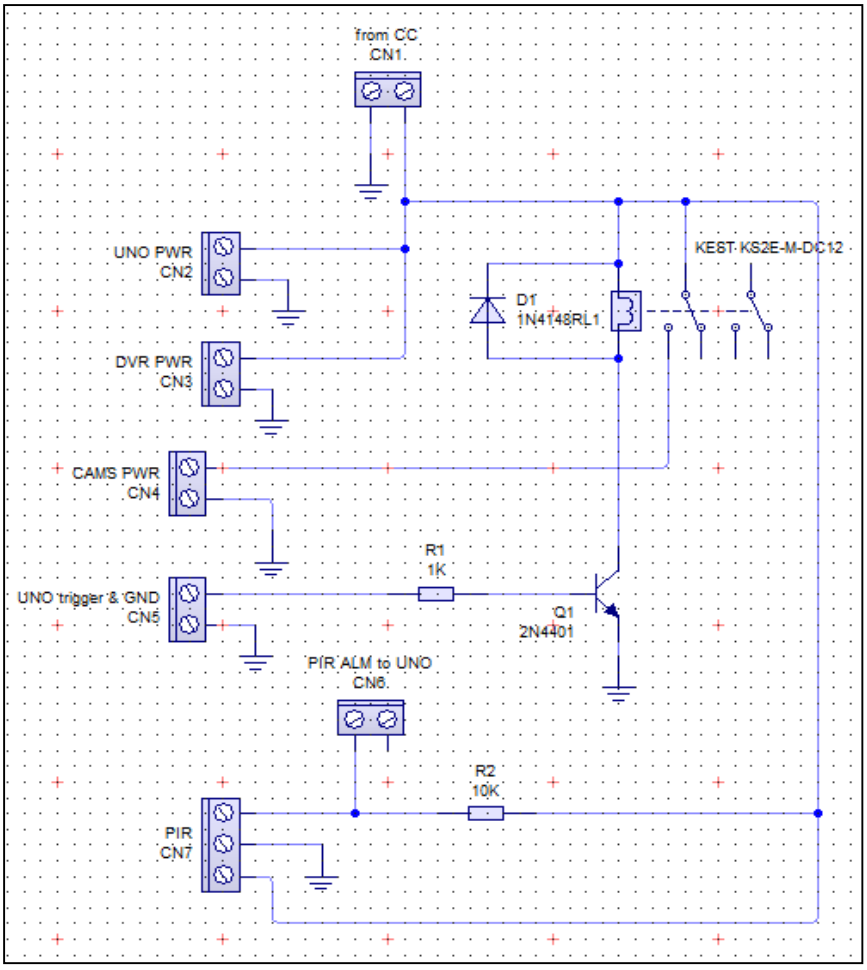


Fig. 3.37. Preliminary schematic of the Wake-up prototype

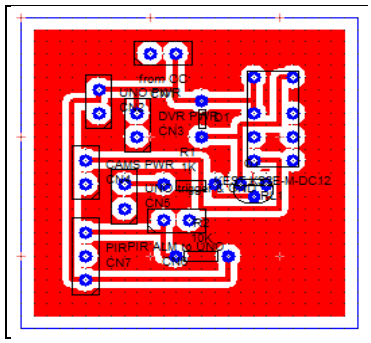


Fig. 3.38. Preliminary PCB design

To help quantify the benefit of toggling the camera power with motion, three potential scenarios of power consumption were considered: (1) basic off-grid; (2) wake-up off-grid with 18 hours active per day; and (3) wake-up off-grid with eight hours active per day. For a single P550 camera, the calculations were done for four and eight cameras powered from the same power station. The prototypes at Rio Bosque would be Scenario 1b, a basic off-grid setup (see Table X).

TABLE X
SAMPLE USAGE SCENARIOS

Basic Off-Grid
Scenario 1: DVR & cams always on, motion record *Assumption - active 100% of the day (24 hrs)*
a. 1 camera
b. 4 camera
c. 8 cameras
Wake-Up (Theoretical)
Scenario 2: DVR always on, motion record *Assumption - active 75% of the day (18 hrs)*
a. 1 camera
b. 4 cameras
c. 8 cameras
Scenario 3: DVR always on, motion record *Assumption - active 33.33% of the day (8 hrs)*
a. 1 camera
b. 4 cameras
c. 8 cameras

Table XI shows the power consumption results when considering the three scenarios. For example, if there were only 8 hours of activity per day, the total consumption could be reduced from 391.68 Whrs/day in the always-on configuration to 263.04 Whrs/day. The associated battery capacity is outlined in Table XII.

TABLE XI
POWER CONSUMPTION (Whrs/day)

Scenario	Hours Active per Day	Number of IR Cameras		
		1	4	8
quoted	24	720	1152	1728
1	24	246.96	391.68	584.64
2	18	234.9	343.44	488.16
3	8	214.8	263.04	327.36

TABLE XII
BATTERY CAPACITY (Ahrs)

Scenario	Hours Active per Day	Number of IR Cameras		
		1	4	8
quoted	24	72	115.2	172.8
1	24	24.696	39.168	58.464
2	18	23.49	34.344	48.816
3	8	21.48	26.304	32.736

Any reduction in the size of the battery bank would benefit field studies because of the heavy weight of lead acid batteries. Also, the lower the load's power consumption and battery capacity, the smaller the necessary solar panel array needed to support it. For each scenario, the daily solar panel output are provided in Table XIII, where the basic off-grid setup required 71.8 Ahrs/day and a system with only eight hours of activity per day required 48.2 Ahrs/day. This corresponded to a Windy Nation™ solar panel array of 200 W instead of 300 W for the basic off-grid.

TABLE XIII
SOLAR PANEL OUTPUT (Ahrs/day)

Scenario	Hours Active per Day	Number of IR Cameras		
		1	4	8
quoted	24	132	211.2	316.8
1	24	45.276	71.808	107.184
2	18	43.065	62.964	89.496
3	8	39.38	48.224	60.016

3.4.7 Outdoor Equipment Study with Undergraduate Team

Following the summer RET program, four undergraduate engineering students participated in system power consumption questions, refining the design, and conducting power tests. The equipment was moved to a watering hole on the other side of the tree line at IDB to view roaming wildlife (see Fig. 3.39).

Fig. 3.39. Cameras facing a small pond

Once the components inside the box were disconnected, the box slid away from the frame, the solar panels were dismounted from the hinges, transported it to a watering hole about 500 yards away, and reconstructed it in less than hour (see Fig. 3.40). The ability to disconnect the major pieces (solar panels, equipment box, and the

frame) and relocate it on the property illustrated one of the many benefits to the user-built off-grid system. Since successful continuous power was observed with the RET trial at IDB, this next opportunity attempted to resize the off-grid support with the equipment on hand or at reasonable additional cost. Smaller combinations for off-grid support were explored in hopes of reducing cost, weight of the batteries, and physical footprint. Mounted on t-posts, the cameras would view open-area movement. With this camera positioning, motion was detected constantly either by wildlife activity or simply vegetation blowing in the wind or clouds overhead. Exhausting the system with open-view cameras was intended.

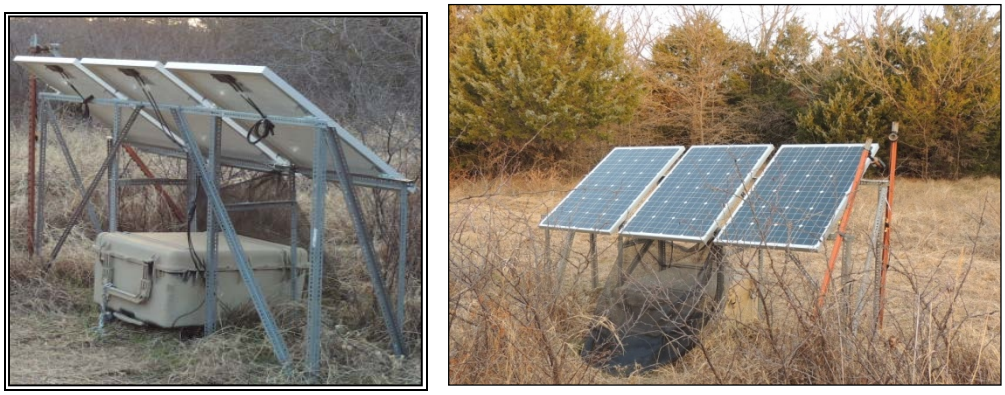


Fig. 3.40. Setup by the pond at IDB

In the October test, the setup temporarily comprised of one DVR, five cameras, two 100 Ahr batteries, 30 A charge controller, and a 100 W solar panel. Only one solar panel was used, to lower cost and physical footprint, although outages and a slower recharge rate were anticipated with the reduced solar array output. Obviously 100 W was not enough solar power, but it helped to witness the effects of under sizing the off-grid system. If the battery fell below the load cutoff threshold (11.1 V), and once the solar panels provided energy, the charge controller recharged the battery. Once the battery level rose above threshold (12.5 V), the charge controller would automatically

reconnect power to the load terminal, while continuing to recharge the battery. The charge controller was set to Normal Mode to continuously supply power to the load from the battery (when above threshold).

There were indications of wildlife activity in many directions around the pond, so a fifth camera was added to the prototype. Considering this extra camera, the revised daily power consumption was 439.92 Whrs/day, requiring a minimum of 43.99 Ahrs battery capacity. To recharge the system would require 80.65 Ahrs/day of solar panel output, still in the 300 W solar panel array sizing with Windy Nation^{TM}. panels Only the 200 Ahr battery bank was available during this testing from the preliminary design. According to calculations, the 200 Ahr battery bank should require 236.66 Ahrs/day of solar panel output, placing the array at over 400 W. Therefore, some outages were anticipated.

In the November test, the setup comprised of one DVR, five cameras, one 100 Ahr battery, 30 A charge controller, and a 100 W solar panel. The behavior of the system to only one 100 Ahr battery in the bank was observed to see if the single 62 lb battery would suffice at Rio Bosque. Five cameras and a single DVR with one 100 W solar panel drained the batteries to threshold and recharged, further testing the DVR's response to power outages than the October test. Five cameras, a DVR, and a 100 Ahr battery, yielded a solar panel output requirement of 136.66 Ahrs/day.

Through both October and November, the system withstood insufficient power events, such as heavy cloud cover, when the system depended solely on the battery storage, and also semi-cloudy days increasing the battery recharge time. The DVR power status was compared to a corresponding level of inferred solar radiation quality

that was theoretically activating the solar panels. Available cloud cover data was pulled from Weather Underground™ by The Weather Channel® for the testing periods, and was compared to samples of the DVR power status at corresponding time stamps. The comparison helped identify if overnight power losses could be attributed to previous periods of cloud cover. Samples were taken at dawn and dusk, when wildlife activity was more likely to occur at the IDB test site. Sampling at midnight and noon alone did not provide enough data points to reflect the solar quality throughout the day for obvious reasons. For example, if a large cloud cluster passed over the system for just the noon hour when the sample was taken, that could lead to an incorrect assumption that the entire day was cloudy and lacked solar energy to support the system. Such an assumption might suggest that the batteries are working well through storms, when in reality the data was not representative of the amount of potentially usable solar energy. The opposite could happen as well, where the sample is during the one hour of sunlight for the day, suggesting the system is not performing well even in direct sun, when it was actually cloudy throughout most of the day.

Therefore, the following times were sampled for each day: 00:53, 06:53, 09:53, 12:53, 15:53, and 18:53 (24 hour clock). Table XIV shows the methodology for interpreting potential solar quality received by the solar panels. If the sample was before sunrise or after sunset (nighttime), the inferred solar radiation quality was categorized as (1) bad, regardless of cloud cover.

TABLE XIV
CLOUD COVER AND SOLAR QUALITY

Cloud Cover Rank	Cloud Cover Description	Solar Quality Rank	Solar Quality Description
1	Clear	4	good
2	Scattered Clouds	3	fair
3	Partly Cloudy	3	fair
4	Mostly Cloudy	2	poor
5	Overcast	2	poor
6	Light Rain/Snow	1	bad
7	Rain	1	bad
8	Heavy Rain	1	bad
9	Thunderstorms and Rain	1	bad

Fig. 3.41 and Fig. 42 show the inferred solar quality and the load status for the October field deployment, respectively. From these plots the rising and setting of the sun can be compared to the load status through the day and overnight, while also providing an indication of cloud cover. Load power was automatically switched off by the charge controller to protect the battery (11.1 V threshold) after prolonged periods without sufficient sunlight, such as the 21 hour span experienced October 13-16. Sustained heavy cloud cover reduced solar quality, but once the storm passed to expose clear skies, the system recharged the batteries to the minimum for safe use (11.4 V) in approximately 5 hours and the load resumed normal operation with the stored configurations. This was supported by the theoretical equation provided by [27] defining time to recharge to full = [(DOD/100) x Rated Capacity (Ahr) / Rated Output of Charger (Amps)] + 2 hours. For the 200 Ahr and 50% DOD using the 30 A charge controller, it would take 5.33 hours to recharge to full.

During the November deployment, the system endured several cloud cover episodes: 11/4-11/6, 11/16, and 11/19-11/26 (see Fig. 3.43 and Fig. 3.44). Aside from

normal mode (0 hours delay) on the charge controller, there were only settings to delay power on after sunrise on this charge controller, which suggests that some might use it for applications without nighttime power demands. For observation starting 11/27, the charge controller mode was changed from normal mode (power load always) to a four hour delay mode, disconnecting load power from sunset to four hours after sunrise. The battery size of the preliminary prototype installed at the IDB tests was reduced to 66 Ahr for the final prototype.

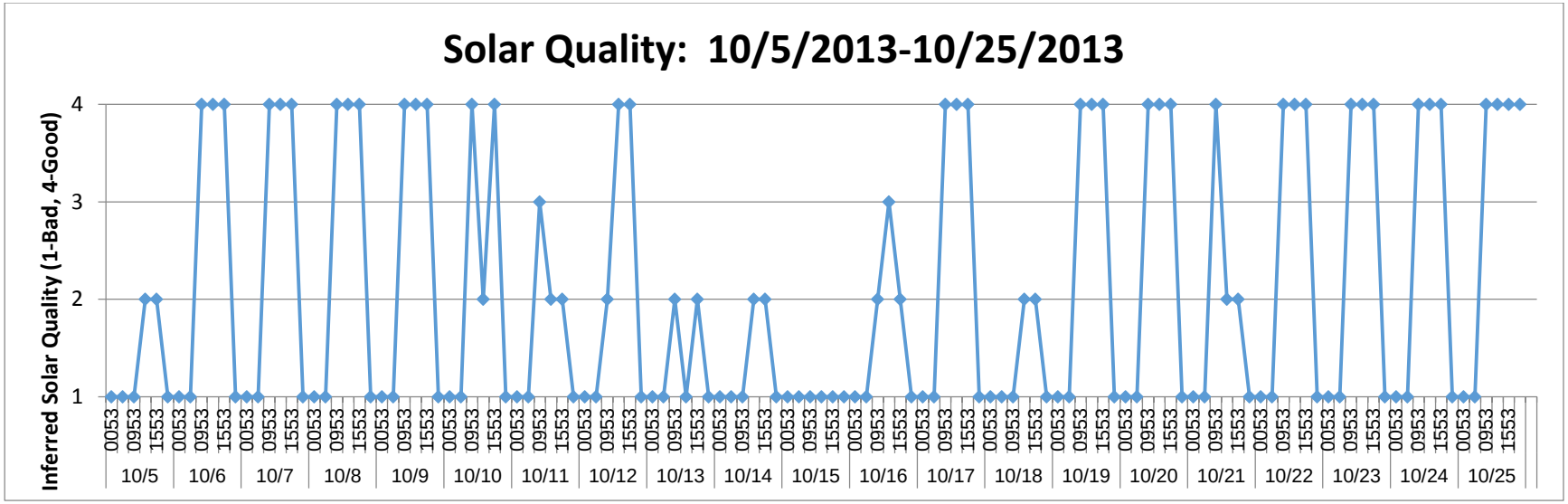


Fig. 3.41. Solar quality for October

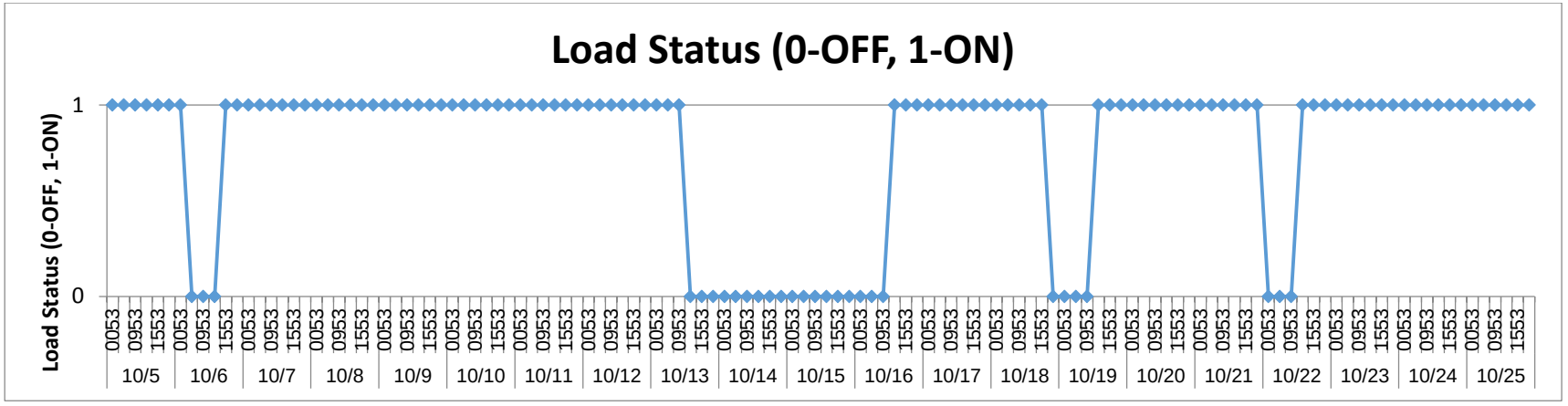


Fig. 3.42. Load status for October

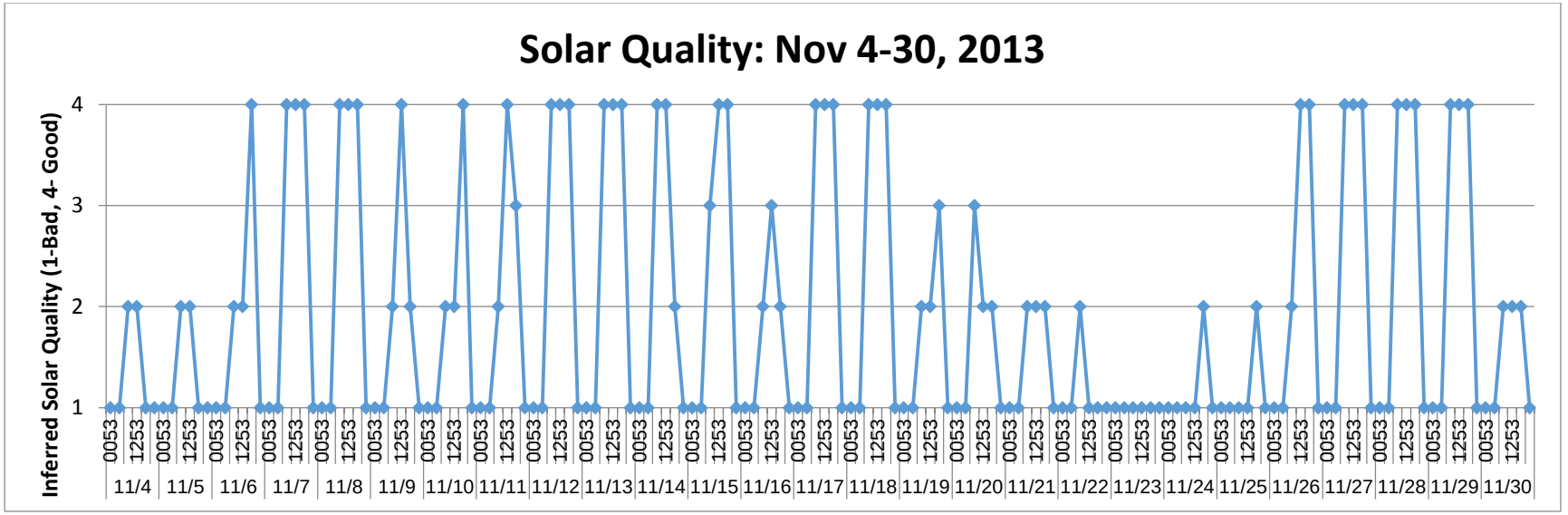


Fig. 3.43. Solar quality for November

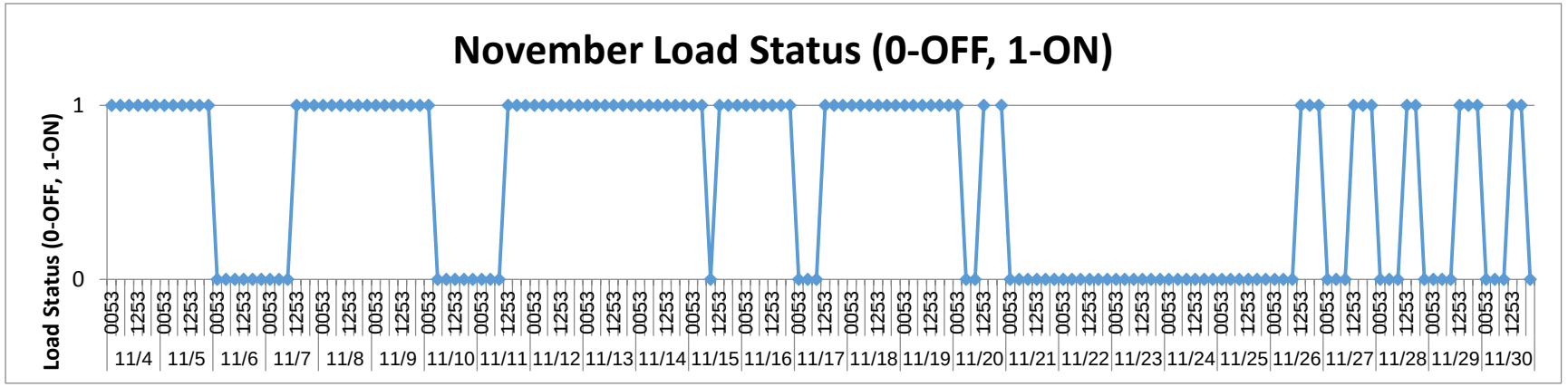


Fig. 3.44. Load status for November

Overall, the results supported the original goal of developing an off-grid video system to record wildlife behavior, uninhibited by human presence during observation. Exciting footage was captured over the two month-long deployments at IDB, including a buck chasing doe, a black bird taking flight toward the camera, two different bucks scraping a tree, and a variety of other events. Fig. 3.45 through Fig. 3.48 some still-shots from the videos captured at the watering hole. Chasing and tree-scraping scenes were particularly interesting for this project because of how it addressed the end goal: archiving meaningful behavior in situ. Similar video recording of this scraping behavior of bucks was noted in the study by Huckschlag [13].

Fig. 3.45. Bird taking flight toward the camera

Fig. 3.46. Samples of a small buck, a doe running and a curious buck

Fig. 3.47. Buck scraping a tree at night (sequence)

Fig. 3.48. Chase scene on channel 5 (sequence)

From these month-long trials in October and November, this system required minimal maintenance compared to other systems with more frequent data collection and/or battery replacement. Toward the end of the November trial, the cameras began providing occasional racing lines in the video feed, during all hours of the day and night. The cause was not identified, though it is likely the prolonged heat of being placed in direct sunlight was an issue for the cameras. The cameras would need to be shaded in future above-ground trials. Since the cameras were commercial products backed by warranty, the cameras can be replaced at the field site.

CHAPTER 4

FINAL TESTING AND DISCUSSION

4.1 Final Site at El Paso, Texas

4.1.1 Site Layout

In late January 2014, Lois Balin of Texas Parks and Wildlife Department (TPWD), offered several potential burrowing owl sites for camera installation; the decision was made to use site A and site B. Site A was the most successful artificial burrow site at the park annually, increasing the likelihood that an owl would occupy the camera-equipped burrow. Site A was nearest to the parking lot and picnic tables, allowing park visitors to see the setup and encourage them to follow the local conservation project. Also, site B was chosen because it was known to be successful year after year, and both were in need of repair. To help reduce erosion around the tunnels, the biologists started reinforcing the tunnel entrances with rocks. A perch was added to encourage the owls to visit and nest. Local volunteers worked together to install two prototypes of the research in January 2014 (shown in Fig. 4.1 to Fig. 4.6).

Fig. 4.1. Entrance to and installation of the artificial burrow

Fig. 4.2. Running the cables between access bins

Fig. 4.3. Camera mount and tunnel access

Fig. 4.4. Installing the frame and equipment box

Fig. 4.5. Front (angled) and rear view of the prototype

After installing the box, a wood brace was placed to help reduce warping from the weight of the dirt compressing the long sides of the case (see Fig. 4.6).

Fig. 4.6. Equipment box at Rio Bosque

When digging up site A, a couple of organisms were found in the old den. Balin took the opportunity to see if there was an owl inside, and check for an identification band for her research. The team witnessed first-hand Balin sealing the tunnels, and peering into the den from above. Incredibly, both a juvenile owl and a cottontail rabbit were found together in the den. Fig. 4.7 is a picture of the owl discovered, and the

identification band indicated that this was a returning individual. The owl was cautiously removed from the den during the system installation and observation showed that the individual returned later that day.

Fig. 4.7. Burrowing owl on install day

4.1.2 Performance

Although set to motion record using the quick-set record mode, the digital video recording (DVR) device consistently detected false instances of motion, continuously recording the camera feeds from all channels. This produced an overwhelming amount of empty footage in which there was no actual motion in the frame, despite the DVR detecting motion. To troubleshoot, the motion sensitivity feature of the DVR was lowered to minimum, although perhaps small dust particles in the frame were detected by the DVR's algorithm.

Despite the quick-set default motion record working properly in the den height trials and at the TPWD office, it continued to false record nonstop at the field setup (see Fig. 4.8). Configurations and clock settings are automatically stored for weeks without power using the small internal battery on the DVR [22], so it was unlikely the DVR resorted to the default settings with unexpected power losses in the field. The DVR was also set to auto-reboot each Saturday at noon to refresh the system and resume as

configured prior to the safe shut-down and restart. There were no underexposed objects to produce shadows, which can falsely trigger motion, because this design used a small den space with full infrared (IR) illumination. On the opposite notion, overexposing the den might have created issues, but was again unlikely because the quick-set motion record worked properly in the den height trials.

When reducing the sensitivity did not improve the performance at the burrowing owl site, the DVR was set to Scheduled Record Mode with motion detection enabled, thus resolving the issue again. Quick-set record mode was convenient, but unreliable in some applications, as experienced one time at Isle du Bois (IDB) and again at Rio Bosque Wetlands Park (Rio Bosque). Scheduled Record Mode took more time to configure and teach to other users, but improved reliability as witnessed in this research.

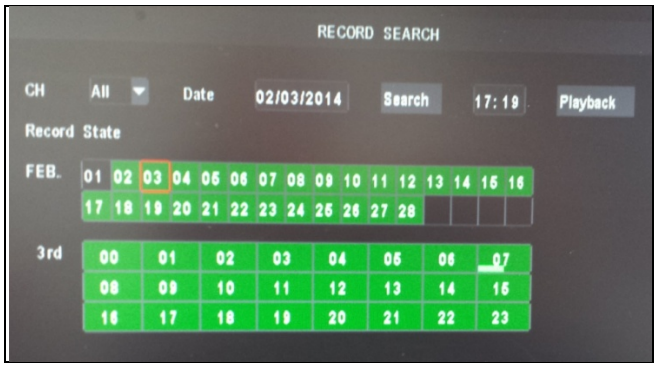


Fig. 4.8. Screen capture of February field test

After a month-long deploy in February 2014, the batteries were still fully charged and the 24/7 recordings showed that the system did not experience power loss. Therefore, the reduced battery capacity was a good adjustment to the off-grid system size. Without the need to swap batteries, this was a critical improvement to the three day swap required by [10] and the two to four day recording period achieved by Cox [2]

in 2012. Even after over 30 days recorded, there was still 11 GB of the 500 GB storage space remaining on the hard disk drive (HDD). This was with the DVR falsely detecting motion and recording nonstop, yet it still outperformed the storage capacity of the three day data retrieval for [10].

Helping to address Lois Balin of TPWD's banding research, the tunnel camera view showed whether or not owls entering the nest were uncharted to the area because the leg could be checked for a band (see Fig. 4.9). Interestingly, this particular owl in Fig. 4.9 did not turn to enter the den, but instead backed out of the tunnel. Although the faint red glow of the IR LEDs seemed to intimidate this individual, other owls were observed in and out of the den and tunnel system throughout the month (see Fig. 4.10). A camera was added to an older nearby burrow after a breeding pair was seen occupying the nest and had laid nine eggs. Incubation and preening (shown in Fig. 4.10) was recorded by the prototype, and the eggs have yet to hatch at the time of this composition.

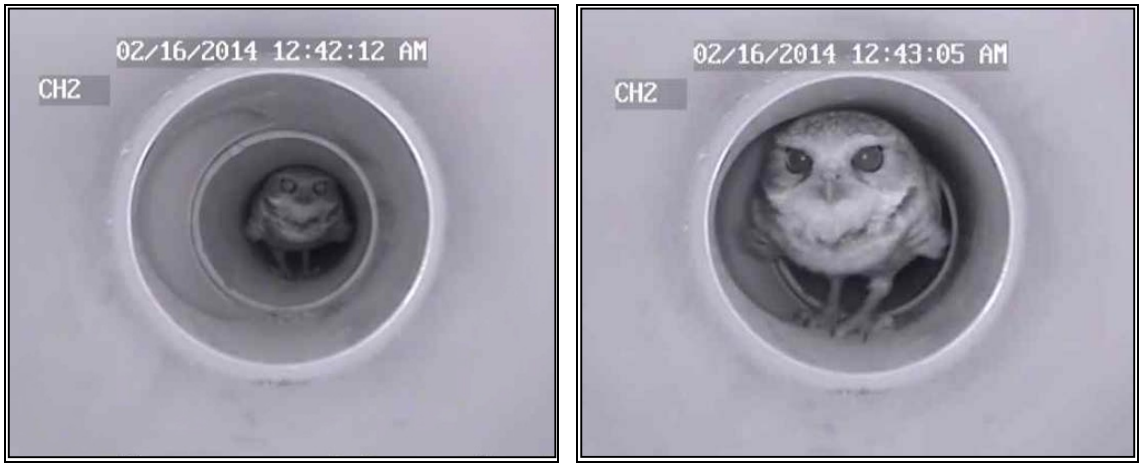


Fig. 4.9. Burrowing owl at the far- and close-end of the tunnel

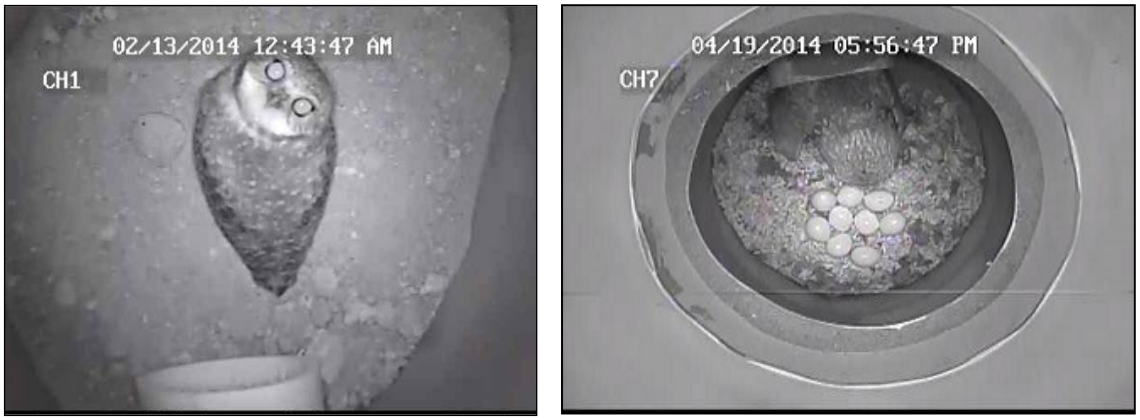


Fig. 4.10. An owl exploring and an incubating owl

The tunnel cameras provided excellent clarity of incoming and exiting organisms, facilitating the identification of food brought into the den by owls, predation events on the nest, and many others. Other mammals explored the burrow, like the rabbit that entered site A at the end of March (see Fig. 4.11) bore several scars which might help identify this individual among others.

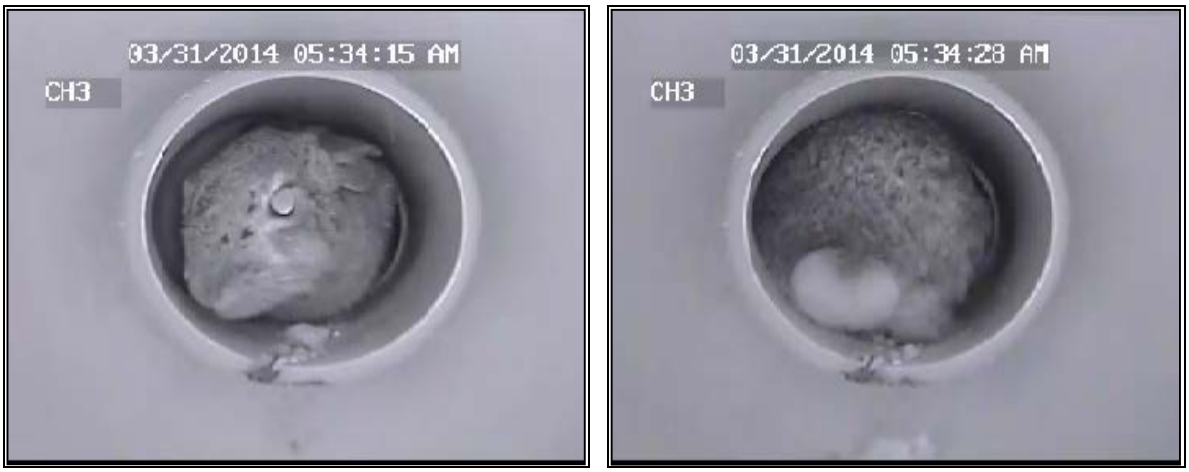


Fig. 4.11. Cottontail rabbit at site A

4.2 Broader Impacts

Applying DVR technology, this work offered the potential to advance current conservation efforts. The innovation behind this design was not in the individual

components, but in their collective application. Undeniably, TPWD's Balin needed research data that this project was able to provide. In addition, it was a valuable opportunity that bridged a gap in technology application between engineering and environmental science, especially for conservation challenges. Interdisciplinary partnerships are necessary for developing stand-alone environmental observation systems capable of providing valuable data for scientists to use toward further research [29]. By the time prototypes were installed at Rio Bosque, the project engaged diverse participants, ranging from students and scientists to educators and community members.

System development and the generation of training materials was the focus for this research, while the data acquired at the final sites at Rio Bosque will be used toward conservation studies by biologists at TPWD and University of Texas at El Paso. This project facilitated the advancement of knowledge on a species of international research interest and concern, the western burrowing owl. A method was developed for collecting rich visual data, beneficial to scientists across disciplines, offering potential to advance research in diverse fields centered around science, technology, engineering, and mathematics (STEM). Furthermore, project expansions could strengthen the research partnership between the University of North Texas (UNT, Denton, Texas) and TPWD. Also, the archived video clips could be used in classrooms to teach students about scientific observations, wildlife conservation, and related technology applications.

Although the prototype was designed with burrowing owls at Rio Bosque in mind, the model can be modified to suit a number of applications for scientists and enthusiasts alike. For example, the prototype could be modified to view a song bird nest in a

residential backyard or to study other species of conservation concern. This user-built video system could also be used to advance wildlife management studies, such as deer surveys and habitat characterizations, that could benefit from being supported off-grid. To increase knowledge of rehabilitated mammals in captivity, the cameras could be installed in places like the nearby Big Cat Sanctuary in Boyd, Texas, which has an internship program that could be an avenue to link technology with other STEM disciplines.

Communicating this research helped others to envision applications of modern technology (i.e. CCTV security system), while exploring new technology in the design (i.e. alternative power). With each new participant the project efforts were disseminated, addressing the research progress and remaining questions. At each new site, this information was communicated to the local biologists and Park Rangers. Project efforts have also been shared in a variety of invited talks, ranging from a local 5th grade audience to an undergraduate electrical engineering class. As of March 2014, TPWD's Lois Balin began posting owl sightings from the prototype to the El Paso Urban Wildlife-Texas Parks and Wildlife Facebook™ page.

In addition, the Research Experiences for Teachers (RET, NSF Grant Num. 1132585) participants (shown in Fig. 4.12) gained a unique hands-on experience they shared in their classrooms about working alongside engineering students, faculty, and TPWD biologists. A blog of their research can be found at <www.untwildwatch.blogspot.com>. Involvement in this research may propel the undergraduate participants toward unique, STEM interdisciplinary research, with relevance to course theory and projects, including: analog and digital design, digital

signal processing, wireless communications, off-grid systems, and senior design classes.

Fig. 4.12. Initial field study at IDB with RET

4.3 Avenues for Continued Research

Using this research as a base, others could improve the prototype design and answer some of the remaining questions pertaining to the wildlife monitoring stations. A few potential expansions might include: (1) transitioning to a more efficient long-term design, with power management; (2) establishing a network of these stations; and (3) adding environmental data collection, among others.

4.3.1 Modifications to Improve Efficiency

Future researchers could improve the performance of the motion-detection technique for this system, aiming to reduce the occurrence of false alarms. Improving the connection mechanism at the terminals, similar to the power strip in [10], might improve implementation because the connections on the charge controller were difficult to secure on-site.

While considering the charge controller, a better type of unit could improve the performance of the off-grid system. There are maximum power point tracker (MPPT) designs that would improve efficiency from the solar panels. Some charge controllers simultaneously trickle charge the battery and supply the load from the solar panels.

Solar tracking systems use motors to keep the surface of the solar panel at the optimal angle to the sun, and some systems combine wind and solar power [8]. Incorporating a small vertical axis wind turbine (VAWT) would prove useful at windy sites like Rio Bosque.

In the Wake-up design, the Arduino™ microcontroller can be placed in sleep mode and have it wake up to excitation from the passive infrared (PIR) sensor, helping to address the concern that the Arduino™ microcontroller consumes excess power for the task at hand. Since the microcontroller would already be inside the equipment box, a temperature sensor and another relay could be used to detect when ambient temperature inside the equipment box becomes excessive and shut off power to the DVR for overheat protection and a small DC operated fan could be switched on to reduce cooling time. Improvements to the off-grid components could reduce the physical footprint and cost.

4.3.2 Wireless Access and Establishing a Multi-Agent Network

In addition to improving efficiency and replicating this system to monitor additional sites, researchers could apply networking techniques between sites. Earlier in this paper, remote access to the DVR was discussed. A local area network (LAN) connection between the DVR and the main router would allow remote access to the

DVR. This wired network would be unrealistic for the El Paso setup, while a wireless point-to-point range extension might be feasible to take the signal from Rio Bosque Wetlands Park to the TPWD office in El Paso, Texas (approximately 17.7 km). Point-to-point wireless bridges essentially extend the range of a primary router to an area outside of coverage such as this. There exists a plethora of information on wireless communication techniques for video content, becoming a hearty research topic with considerations for range, bandwidth, compatibility, reliability, and power consumption of the radio module. Another scaling issue might occur when placing more than one DVR on the network. An access point at each DVR could allow communication with the central router, but bandwidth and quality could certainly suffer with increased data volume.

Power management techniques could be extended to the wireless networking scheme to transmit only meaningful data-rich video, and only when motion is present at the camera. This could avoid unnecessary power consumption used to transmit empty footage. A challenge moving forward could be coordinating when the host receives the signal for video download, especially if the system only receives power at the occurrence of movement. A similar comparison would be attempted to place a call when the receiving phone is turned off, preventing communication until power is restored. Perhaps a solution would be to power the system all day once per week for file access, while also serving as a scheduled time to charge the internal battery responsible for keeping the DVR time/date information.

Recent discussions with faculty at the Department of Electrical Engineering at UNT identified a need for two expansions: a team to work on the long distance

transmission from Rio Bosque to the TPWD office in El Paso; and another team to locally explore a larger network of video nodes at more owl sites with short range communication, utilizing the Default Tolerant Network adaptive mesh protocol. The local mesh network of sites could then transmit to a base station at Rio Bosque for long distance transmission to the TPWD main office in El Paso, creating a conglomerate of digital and wireless technology.

4.3.3 Incorporating Video Data to Environmental Monitoring Stations

Next, the network of wildlife monitoring stations could move toward adding the data to the Texas Environmental Observatory (TEO) [21, 30], which provides a repository of environmental measurements for parameters such as temperature, humidity, and soil moisture. Formed under prior research as the CRI: IAD Infrastructure for Environmental Monitoring and Modeling using Large-Scale Sensor Networks (NSF CNS-0709285) at UNT, the TEO [30] has several weather stations scattered across Denton, Texas for collecting environmental data. A long-term site at the City of Denton Clear Creek National Heritage Center (NHC) could be a wireless hop to the TEO base station at UNT. Combining video and environmental data for public reference would support the discussion in [29].

In 2006, the National Science Foundation (NSF) [29] addressed the need for long-term sensing of the environment and discussed the use of in situ sensors for gaining a broader understanding of the Earth. Building upon the value of environmental data collection discussed in [29], the wildlife video footage could be incorporated with environmental data to further characterize the habitat at a given moment. Researchers

at UNT have already been working toward multimedia test benches for environmental monitoring [31].

4.3.4 Other Extensions

Furthermore, researchers could revisit hard drive swapping because it is likely more cost effective in a more suitable environment. The proprietary format of the DVR internal hard drive imposed challenges for the transfer of data and knowledge from one research team to another. However, there may be other DVRs that offer a hot-swappable hard drive discussed by some wildlife video systems [8].

As with any video archiving project, the challenge of big data arises as tremendous amounts of footage accumulates. An interesting solution would be to apply some recent work by [32], in which baseball video files were analyzed to identify clips by major action type. While [32] focused on extracting highlights of sports videos, the owl footage could be filtered using research-developed digital processing similar to [32]. Use of an activity analyzer to categorize video segments by movement or activity, could simplify the process of studying the birds' behavior. For example, the clips could be separated into similar behavior like entering/exiting the nest or eggs hatching. However, the design discussed in [32] relied on color features of the video frames, while the data recorded by this video monitoring station was entirely infrared, appearing monochrome.

Others could also seek to improve the performance of the compression algorithms and video analyses. These could not be explored with the selected Swann™ system because the software development kit (SDK) was not available, preventing customization of DVR processing. In a more customizable system, improvements could

be made to video compression by taking advantage of known source qualities. A background modeling unit [18] could be used due to the static mount of the cameras and relatively unchanging background in the burrow, or by comparing combinations of features to signify movement between frames. The latter could be described as a two-dimensional graph where the axes could be specific features and a slope dividing normal and abnormal feature combinations to trigger movement. These features might be saturation levels of a certain color or texture.

Creating a portable power station, or essentially a scaled down version of the prototype, could be used to connect a standard display monitor on-site and could be used for demonstrations. Using a smaller battery bank, charge controller, and solar array the portable power station to power a monitor in the field would allow verification of the video feed on-site without an extension cord from a power inverter in the car.

Some might even respond to Balin's research use of metal identification tags with future work by adding radio-frequency identification (RFID) technology. RFID tagging could be used to trigger recording in the burrow, improve the logging of individual owl activity, and could even expand to GPS tags for tracking migration.

Continued research was explored by the author of this research in a proposal writing experience as a graduate course assignment at UNT. The sample three-year proposal titled the Wild Watch Expansion Project (WWEP) described UNT resources and potential external collaborators for research. This could be revisited and submitted for NSF funding to support undergraduate students, graduate students, and a post doc researcher. Others could build upon prior technical research completed here and further incorporate public outreach to increase awareness of technology in environmental

studies. A natural collaboration could follow with local boys and girls clubs, as well as engineering education outreach partners in the Dallas-Fort Worth area. Collaborators could include The Global Owl Project (GLOW), UNT, TPWD, the Wildlife Society, the Wildlife Conservation Society, United States Fish and Wildlife Service (USFWS), and the National Park Service Teacher Ranger Teacher Program.

CHAPTER 5

CONCLUSION

Through this research, an off-grid video monitoring system was developed and implemented to aid in the burrowing owl conservation efforts of biologists with the Texas Parks and Wildlife Department (TPWD). With the species population on a downward trend, the western burrowing owl is a bird of conservational concern. Researchers with TPWD combat the lack of natural habitat with the installation of artificial burrows at Rio Bosque Wetlands Conservation Park. The system developed in this thesis changed the once time-consuming and unpredictable means of observing the owls at these artificial sites into a simple matter of reviewing archived videos of burrow activity.

While vendor-built digital video recording (DVR) systems exist for wildlife studies, this application to underground burrows was an opportunity to experiment with a user-built system design. An infrared (IR) camera facing out of the two entrances and one IR camera overlooking the den, equipped the TPWD biologists to answer more of their research questions such as owl food selection, nesting behavior, and predation events on the burrow. The solar powered video system was installed with access for maintenance and modification in mind, along with supplemental guides and videos generated to help disseminate project details from one research team to the next.

APPENDIX A

SAMPLE MOTION DETECTION CODE

```
/ *Revised Motion Detection Code 7/11/2013
 * source http://www.ladyada.net/learn/sensors/pir.html
 * PIR sensor tester
 * comments added pertaining to this research
 */

int trigger = 12;               // choose the pin for the LED
int pir = 2;              // choose the input pin (for PIR sensor)
int pirState = LOW;             // we start, assuming no motion detected
int val = 0;                    // variable for reading the pin status

void setup() {
  pinMode(trigger, OUTPUT);      // declare LED as output
  pinMode(pir, INPUT);     // declare sensor as input

  Serial.begin(9600);
}
void loop(){
  val = digitalRead(pir);  // read input value
  if (val == LOW) {           // check if the input is LOW (LOW=motion)
    digitalWrite(trigger, HIGH);  // turn LED ON (trigger relay)
    if (pirState == LOW) {
      // we have just turned on, //new motion event
      Serial.println("Motion detected!");
      // We only want to print on the output change, not state
      pirState = HIGH; //hold motion state
      }
      delay(5000);
  }
  else {  //no motion
    digitalWrite(trigger, LOW); // turn LED OFF
    if (pirState == HIGH){
      // we have just turned off
      Serial.println("Motion ended!");
      // We only want to print on the output change, not state
      pirState = LOW;  // exit motion state
    }
  }
}
```

APPENDIX B

PARTS LIST FOR OFF-GRID PROTOTYPE AT RIO BOSQUE

Video System	Price (USD)	Quantity	Cost (USD)
Swann™ SWDVK-825504 Kit: eight-channel DVR & four cameras		1	400
Subtotal			$400
Off-grid Support	**Price (USD)**	**Quantity**	**Cost (USD)**
Windy Nation™ 300W Off-Grid Kit Polycrystalline solar panels and 30A CC	435	1	435
12V 33Ahr Deep Cycle Marine Lead Acid Battery GPL-U1T (Lifeline®)	140	2	280
Pelican™ box 1690 w/o foam	290	1	290
Subtotal			$1005
Solar Panel Mount	**Price (USD)**	**Quantity**	**Cost (USD)**
1-1/4" x 48" Galvanized Pipe	23.1	3	69.3
1-1/4" x 18" Galvanized Pipe	9.91	2	19.82
1-1/4" Galvanized Cap Fitting	3.21	2	6.42
1-1/4" Galvanized Tee Fitting	6.6	2	13.2
5/16" x 1-3/4" x 3-1/4" U-bolt	1.3	6	7.8
5 Gallon Plastic Bucket	2.78	2	5.56
Quikrete™ 50-lb (Fast-Set Concrete Mix)	4.98	1	4.98
Chain (sold by the foot)	2.51	3	7.53
Outdoor security locks (set of 4)	29.97	1	29.97
Subtotal			$164.58
Camera Mounts and Access	**Price (USD)**	**Quantity**	**Cost (USD)**
6" Atrium Grate	9	3	27
Thin Irrigation Tubing (1 foot)	1	1	1
Vittles Vault™ 15 (4.7 Gallon) www.uplastic.com	21.82	1	43.64
Vittles Vault™ 80 (20 Gallon) www.uplastic.com	50.19	2	100.28
Galvanized bolts and nuts	20	1	20
Fernco™ 4"x2" DWV flexible PVC coupling	9	2	18
Weatherproofing tape	10	1	10
Silicone sealant	10	2	20
Pressure Treated Plywood (1/2"x2"x2")	5.97	1	5.97
Small galvanized hinges	3	2	6
Subtotal			$251.89
Total for Off-Grid Prototype at Rio Bosque Burrow			$1821.47

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